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EXPERIMENTS ON THE AVAILABILITY OF PHOSPHATES AND POTASH IN SOILS.

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During the years 1904 to 1906 plants have been cultivated by pot-culture methods, with and without the aid of fertilizers, in a number of soils which have been brought from different parts of India.

The principal object in view has been to test how far the chemical method, which was advanced by Dyer in 1894 for the estimation of a sufficiency or deficiency of phosphate or potash in soils (*vide* Trans. Chem. Soc., **65.**, 115-167, and Philos. Trans. Royal Soc., Series B., Vol. 194, pp. 235-290) is reliable generally. This method consists in the digestion of the soil at room temperature in a 1 per cent. solution of citric acid for seven days, on six of which the mixture is agitated frequently The solution is then separated by filtration and the phosphoric acid and potash present in it determined. Although such a method is obviously empirical, Dyer standardized the value of its indications by means of a considerable number of soils of the Rothamsted Experiment Station, the agricultural value of which for certain crops is well known. The outcome of his work may be suitably quoted from the second of the papers named. "The probable limit denoting phosphatic deficiency for cereals seems to be, as deduced from this investigation, between ·01 and ·03 per cent. of citric-acid-soluble phosphoric acid in the surface soil. That is to say, a percentage as low as ·01 seems to denote an imperative demand for phosphatic manure, while as much as ·03 would seem to

indicate that there is no such immediate necessity. For root crops, especially turnips, the limit would probably be higher." (Page 269.) "In the paper on the Hoos Field barley soils a tentative conclusion was drawn that the percentage of citric-acid-soluble potash in surface soil, indicative of potash hunger for cereals, would probably be below ·005. On considering the results of the wheat soil analyses and other results obtained in the interim by other workers who have applied the method to other soils known from other experience to be responsive to the influence of potassium salts, the author would now be inclined to modify this conclusion by suggesting that when a soil shows as much as ·01 per cent. of citric-acid-soluble potash, by this process, it may be regarded as not demanding any special application of potassium salts." (Page 275.)

There is one point which must be referred to here. One of the first questions raised, after the publication of Dyer's first paper, was in relation to calcareous soils. Obviously the calcium carbonate present in soils will forthwith react with the citric acid resulting in the formation of calcium citrate and carbonic acid, and the soil is then in contact with a solution of these substances together with any excess of citric acid.

In order to illustrate the bearing of this point, the following figures show the quantities of calcium carbonate in a soil which neutralize each tenth part of the citric acid employed; or since 10 grms. of the acid are employed per 100 grms. of soil, the figures show the percentage of calcium carbonate neutralized by each 1 grm. of the acid.

Citric acid. Grms.	Calcium Carbonate. Grms.
1	1·43
2	2·86
3	4·29
4	5·72
5	7·15
6	8·58
7	10·01
8	11·44
9	12·87
10	14·30

Thus even if the soil contains so high a proportion of calcium carbonate as 7·15 per cent., one half the citric acid remains, and the majority of soils contain considerably less than this. The Rothamsted soil, on which Dr. Dyer worked, contains only about 3 per cent. of calcium carbonate, which would alter the composition of the acid solution in only a minor degree.

Two of the soils which have been included in my experiments contained, however, upwards of 40 per cent. of calcium carbonate, and the citric acid becomes in such a case entirely neutralized.

Dr. Dyer in a postscript to his first paper recommends that in such cases an additional quantity of citric acid corresponding to the quantity of calcium carbonate " might reasonably be added to the solution." If, however, this is done with these highly calcareous soils, the soil constituents are not merely exposed to a solution of citric acid, but citric acid plus a large amount of calcium citrate, and carbonic acid. And indeed an even more important circumstance is the fact that the particles of calcium carbonate are entirely dissolved. Phosphate, which in such a soil may be present in the interior of these particles, is thus brought into actual contact with the solvent, whereas the idea underlying the use of the solvent is, that it will only be in contact with phosphates which are exposed to plant roots or soil-aqueous-solutions, *i.e.*, to phosphates which are on the *exterior* of soil particles. It is hardly, therefore, to be expected that the same result will be obtained as if the soil particles remain as far as possible intact. The circumstance emphasizes a weak point in the method. The following figures show the difference in result obtained (*a*) by the use of the usual 1 per cent. solution, and (*b*) this solution plus the extra citric acid, respectively :—

	By 1 per cent. citric acid.		By sufficient citric acid to neutralize the calcium carbonate plus the usual 1 per cent.	
	P_2O_5.	K_2O.	P_2O_5.	K_2O.
Seeraha soil containing 41·6 per cent. $CaCO_3$	·001	·008	·019	·043
Pusa soil ,, 38·63 ,,	·0003	·0062	·0015	·0085

It will be seen presently that the Seeraha soil is certainly much in need of phosphatic manure, and that potassium sulphate produced positive effects in some cases. The Pusa soil has proved to be much in need of phosphates. If then the extraction had been made with the extra citric acid, the analysis would have indicated a very doubtful requirement of phosphates in the Seeraha soil, and certainly no requirement of potash. The pot-cultures on the other hand leave no doubt that these soils respond to phosphatic manures, and the Seeraha soil probably to potash.

The literature on the subject includes two papers. One by T. B. Wood (Trans. Chem. Soc., 1896, **69,** p. 290), where evidence is produced, showing that the use of the extra quantity of citric acid would have given a result indicative of a sufficiency of readily available phosphates, when in fact the soil responded to phosphatic manures ; the other by Cousins and Hammond (Analyst, 1903, **28,** 238), where the evidence indicates the desirability of using the extra citric acid. This latter evidence relates, however, to land bearing bananas, a crop so entirely different from cereals that a quite different " limiting figure " may be applicable.

It is unfortunate that the conclusions on the subject are so contradictory. It seems to me preferable to adhere to the use of the simple 1 per cent. solution, and if, when it is applied to any particular class of soils, the limiting figure for phosphate or potash, as proved by actual trials with plants, is shown to be different from that which Dyer deduced with the Rothamsted soils, to then adopt this particular limiting figure. It is to be recollected that the method is not merely empirical, but that a limiting figure which is applicable to one description of plant, will not necessarily apply to another plant of widely different botanical character, period of growth, root range, etc. Dyer himself emphasized that the limiting figure he found would not necessarily apply to other crops than cereals, and " that for root crops, especially turnips, the limit would probably be higher" (*vide* ante).

It must be held to be a matter for regret that nearly all who have proposed methods for the estimation of available plant

food, have employed an acid as the solvent. Such solvents necessarily attack the surface of the particles in a manner wholly different from the neutral solutions present in the soil, and as has been pointed out, dissolve up particles of calcium carbonate entirely, thus exposing plant food to the solvent, which in the soil is present in the *interior* of particles. No doubt the quantity of material, which a neutral solvent will dissolve, is much less than would be brought into solution by an acid solvent, and difficulties arise in the determination of such minute quantities, but the fundamental defect attaching to acid solvents nevertheless remains.

The soils which have been subject to experiment at Dehra Dun and (later) at Pusa, comprise the following :—

Soil.	Containing :—		
	Organic Nitrogen. %	Available. P_2O_5 %	Available. K_2O %
Dehra Dun	·181	·146	·022
Seeraha-Behar	·046	·001	·008
Pusa-Behar	·060	·0003	·006
Shillong G	·228	·011	·010
„ B	·193	·005	·012
Bangalore	·059	·0047	·0023
Godavari V	·071	·042	·010
„ R	·084	·011	·005

For cereals, which have so far been principally included, the Dehra Dun soil would be considered sufficiently well supplied with phosphates and potash, and the Godavari V soil probably so ; the other six soils would be expected to respond to phosphates, and four, namely, Seeraha, Pusa, Bangalore and Godavari R to potash.

The first two years' experiments were made while the chemical laboratory was at Dehra Dun, where the conditions for this class of work were in many respects opposed to accuracy. Only a thatched hut was available, and the cultivation jars had to be moved by hand ; nor was any means available for maintaining the moisture very constant, such we now have. But the chief obstacle

proved to be rats and squirrels, which could not be kept away at night and damaged in great measure many of the mature plants.

In some of these cases an estimate of the weight of the entire plants was obtained when their number was reduced in each jar, and these figures aid in drawing conclusions.

The experiments of 1906 made at Pusa were free from such untoward incidents and are in consequence more reliable.

The details are set out in the following pages, but a graphic summary may be here inserted. If the sign + is employed to denote a positive result, whilst the sign – a negative one, ± where the outturn of grain is negative, but that of total dry matter positive, and ? where the indication is doubtful, the nett results will be seen at a glance.

	Phosphate:		Potash:	
	Expected.	Realized.	Expected.	Realized.
Dehra-Dun	–	–	–	......
Seeraha Behar	+	+ + ± +	?	+ + ±
Pusa-Behar	+	+	+	... ..
Shillong G	+	– + +	–	+ + +
„ B	+	– – +	–	– – –
Bangalore	+	+ + +	+	– + –
Godavari V	–	– ± +	–	– – +
„ R	+	+ ± +	+	– ± ±

This representation shows that great dependence may be placed on Dyer's method, as also his limiting figure for phosphates even in soils of a widely different nature. In the whole list, the cultivations have yielded a contradictory result in two cases. The Shillong B soil should have been benefited by phosphates, and if dependence were placed on the experiments at Pusa (carried out with the more perfect appliances), this exception would disappear. The Godavari V soil should hardly have responded to phosphatic manures, whilst it has done so to a greater or less extent.

The effect of potash is similarly characterized by contradictory results in two cases. The Shillong G soil has shown a

positive result where it was hardly to be expected. Dyer's test yielded ·01% K_2O which is his limiting figure. The Bangalore soil should have given a positive result with potash manure, but has done so with only one crop out of three. It is always to be recollected that neither Dr. Dyer nor other experimenters have advanced this method as an absolute one for determining whether it will pay to apply specific fertilizers. On the contrary, it has been regarded as one which must necessarily be employed with some caution. Our knowledge of the nature of the phosphates and the potash compounds which actually exist in the soil is most imperfect, and, as Hall and Amos (Trans. Chem. Soc., 1906, **89**, p. 205), have pointed out, the amount of a soil constituent which passes into solution in a given time depends not only on its nature but also on its mass. Soils in different parts of India differ very widely in composition, and whilst we may apply the 1% solution to them without exception, it does not follow that the same limiting figure will apply equally to all. Finally, the nature of the plant which is grown must always play an important rôle in relation to this limiting figure.

Nevertheless, and although I make these several reservations, there cannot be any doubt that the method is proving generally useful for ordinary agricultural land, enjoying a rotation of crops, one of which is usually a cereal, and that the limiting figure proposed by Dyer is much more generally applicable than might have been expected.

The details of the experiments are set out in the following paragraphs.

Dehra Dun Soil.

This soil is derived from shale and limestone of the Himalayas and is a rich soil with excellent physical characteristics.

The chief analytical data are as follows :—

	Per cent.
$CaCO_3$	·41
Total P_2O_5	·366
Available P_2O_5	**·146**
Available K_2O	**·022**
Organic Nitrogen	·181

It was only employed in one season's experiments when wheat and gram were grown. The outturns were as follows :—

Manure.	Weight of whole crops (grms.).	
	1903-4 Wheat.	1903-4 Gram.
Nil	37·6	45·5
Nitrate	62·0	45·0
Nitrate and phosphate . .	64·3	43·0

The same is set out graphically on the chart No. 1.

The Seeraha Soil.

This soil is representative of a large area in Behar and possesses two chief characteristics ; firstly, it consists entirely of very fine material, and like the whole Indo-Gangetic alluvium contains no stones ; secondly, about one-third of it is chalk.

The following are the chief analytical data :—

$CaCO_3$	41·6
Total P_2O_5	·097
Available P_2O_5	**·001**
Available K_2O	**008**
Organic Nitrogen	·046

It was employed during four seasons, the crops being cereals in each case. The results are set out in the following statement and on chart No. 2, from which it is evident that both phosphate and potash had a definitely positive effect.

Manure.	Weight of whole crop (grms.).				Weight of grain (grms.).			
	1903-4 Wheat.	1904 Murwa.	1904-5 Wheat.	1906 Kodo.	1903-4 Wheat.	1904 Murwa.	1904-5 Wheat.	1906 Kodo.
Nil	2·4	13·3	4·6	24·7	·7	5·4	1·6	12·3
Nitrate	2·1	63·9	11·5	43·9	·6	20·4	6·4	22·7
Nitrate and phosphate	8·3	63·8	20·0	62·4	2·5	26·9	5·9	30·0
Nitrate, phosphate and potash	...	80·3	26·5	...	...	29·1	7·9	...

The Pusa Soil.

This is similar in all respects to the Seeraha soil, but was first included in the experiments in the rainy season of 1906.

The chief analytical data are as follows :—

$CaCO_3$	38·63
Total P_2O_5	·10
Available P_2O_5	**·0003**
Available K_2O	**·0062**
Organic Nitrogen	·060

The crop grown was Kodo (Paspalum scrobiculatum), and the yields were as follows :—

Manure.	Weight of whole crop (grms.).	Weight of grain (grms.).
Nil	41·4	18·7
Nitrate	69·8	20·8
Nitrate and phosphate ...	86·1	27·7

The chart No. 3 illustrates the same result. The same soil has been utilized for similar experiments during the current season, wheat being the crop, and the effect of phosphate is even more marked. The effect of potash was not tested in the rainy season of 1906, but judging by the present season's plants its effect will be negative.

Bangalore Soil.

This is derived from the laterite, and is consequently highly ferruginous. It holds only a low proportion of water. When wet, it drains readily, but at the same time contains so much plastic material, that it is adhesive when damp. The chief analytical data are :—

$CaCO_3$	·066
Total P_2O_5	·052
Available P_2O_5	**·0047**
Available K_2O	**·0023**
Organic Nitrogen	·059

Cultivations were made during three seasons, namely, the monsoons of 1904 and 1906 and the "cold weather" of 1904-05; the crops being Murwa (Eleusine coracana) in the former, wheat in the latter. The plants of the first two seasons were interfered with by the depredations of squirrels and rats, and ultimately the only dependable index of the effect of the manures was the estimated weight of green plants at the time the number of plants in each jar was reduced. It is clear that the phosphate had produced a positive effect at this time, and the cultivations of 1906, which were free from such errors as the above, leave no doubt of this. The effect of potash has been however much less certain, although one might have anticipated a positive result.

The weights of plants were as subjoined and the chart No. 4 refers to them also.

WEIGHT OF CROPS (GRMS.).

Manures.	1904 Murwa.	1904-05 Wheat.	1906 Murwa.
Nil	4·4	·51	10·6
Nitrate	4·15	1·66	39·1
Nitrate and phosphate ...	6·05	1·88	63·3
Nitrate, phosphate and potash	5·02	2·08	43·3

SHILLONG SOILS.

Two soils had been received from Shillong, the one being considered good, the other distinctly infertile. Examination in the chemical laboratory revealed nothing which would account for such a difference. Apart from other characteristics, they have proved to be very similar in their productive powers, and the difference noticed at the place of origin has not at any time exhibited itself in my experiments; both soils have proved to be very fertile. For purposes of differentiation their titles of "good" and "bad" have been retained. They are chiefly characterized by a high proportion of organic matter (3·09 per cent. organic

carbon) and great waterholding capacity. The chief analytical data are as follows :—

		"Good" soil.	"Bad" soil.
$CaCO_3$	...	·088	·025
Total P_2O_5	...	·069	·059
Available P_2O_5	...	**·011**	**·005**
Available K_2O	...	**·010**	**·012**
Organic Nitrogen	...	·228	·193

Murwa was cultivated in the monsoons of 1904 and 1906, and wheat in the cold weather of 1904-5. Like the corresponding plants of the Bangalore soil, these suffered from attacks by rats when the wheat was ripening, and the only index remaining of the effect of the fertilisers was the estimated weight of the green plants when the number in each jar was reduced. The effect of phosphates in these soils is doubtful, whereas it should have been positive in both. This may in part be due to the absence of nitrogenous manure. In other experiments it has frequently been observed that, even though a soil is deficient in available phosphate, a positive effect of this plant food will only be realized if a nitrogenous fertilizer is added at the same time. In such cases, however, there was likewise a deficiency of nitrogen in the soil, and the combined effect of the fertilizers has been just what is found on similarly characterized plots at Rothamsted and Woburn. But when these pot cultures were commenced, the anticipation was that the Shillong soils were so well supplied with nitrogenous organic matter that added nitrate would have little or no effect, and with the limited amount of soil available the distribution of fertilizers was made on this basis. Later, after the effect of the "complete" fertilizer was observed, it was too late to re-arrange the treatment. For several reasons the most reliable result is that obtained in the new pot culture house at Pusa, and with that season's experiment phosphate had a distinctly positive effect. I consider it probable therefore that the indication provided by the analytical method in 1903 was correct and that phosphates would generally react positively with

this soil. The yields are as subjoined and are also illustrated by chart No. 5.

Shillong Soils.

Manures.	"Good." 1904 Murwa.	"Good." 1904-5 Wheat.	"Good." 1906 Murwa.	"Bad." 1904 Murwa.	"Bad." 1904-5 Wheat.	"Bad." 1906 Murwa.
	Weight of whole crop (grms.).					
Nil	52·2	·36*	31·8	42·5	·57*	32·4
Phosphate	40·1	·56*	33·7	50·0	·53*	41·8
Potash	57·5	·45*	43·2	49·5	·54*	31 1
Phosphate, potash and nitrate	74·7	·80*	69·1	56·2	1·06*	74·4
	Weight of grain (grms.).					
Nil	16·7	.	12·0	15·1	...	12·9
Phosphate	16·1	...	16·8	15·6	...	17·5
Potash	19·2	..	16·2	14·7	...	11·6
Phosphate, potash and nitrate	30·0	..	26·5	19·7	...	28·6

* Estimated weight per plant on January 18th. 1905.

The Godavari Soils.

The soil of the Godavari Delta is largely black cotton soil of a very stiff tenacious type and is probably alluvium brought from the similar tracts of the Indian plateau. It was known that much of this land contained low proportions of lime and phosphate as determined in the laboratory, and sufficient earth was sent from two villages for three or four jars. But these portions contained rather more phosphate than was anticipated. The following are the analytical data :

	Vadlamur.	Ragampeta.
$CaCO_3$	·179	·134
Total P_2O_5	·143	·119
Available P_2O_5 .	**·042**	**·011**
Available K_2O	**·010**	**·005**
Organic Nitrogen	·071	·084

Cultivations were made during three seasons, and the yields are set out in the subjoined statement and on chart No. 6.

Godavari Soils.

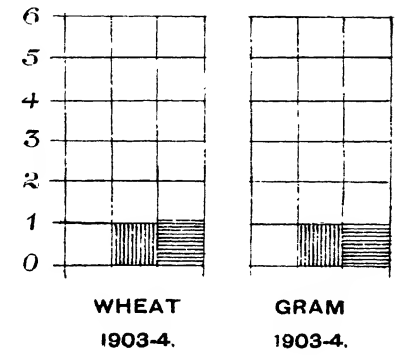
Manures.	Vadlamur. 1904 Murwa.	Vadlamur. 1904-5 Wheat.	Vadlamur. 1906 Murwa.	Ragampeta. 1904 Murwa.	Ragampeta. 1904-5 Wheat.	Ragampeta. 1906 Murwa.
	Weight of whole crop (grms.).					
Nitrate	45·8	18·9	57·0	32·4	22·0	66·4
Nitrate and phosphate ..	29·8	22·2	83·0	28·9	29·0	83·0
Nitrate, phosphate and potash	11·0	23·9	89·1	28·0	26·0	77·2
	Weight of grain (grms.).					
Nitrate	7·5	6·0	24·9	5·2	6·2	31·6
Nitrate and phosphate ...	5·9	5·2	37·4	7·1	5·7	38·5
Nitrate, phosphate and potash	6·0	4·0	39·0	6·2	5·5	31·1

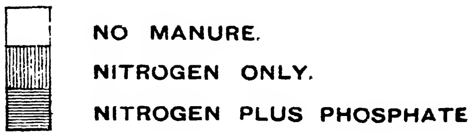
These soils have given the least dependable data of any in the series; "Vadlamur" should hardly have given a positive reaction with phosphate; "Ragampeta" should have done so. As the data show, they have both reacted similarly, the first crop was negative, the second doubtfully positive, the third distinctly positive. The latter, grown under the much more satisfactory conditions at Pusa, is the most reliable.

CHART No. 1.

DEHRA DUN SOIL.

RELATIVE YIELD OF TOTAL CROP

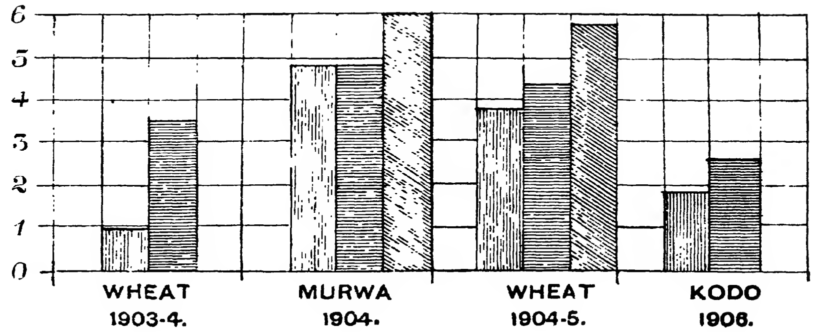




OHART No. 2.

SEERAHA SOIL.

RELATIVE YIELD—TOTAL CROP



RELATIVE YIELD—GRAIN.

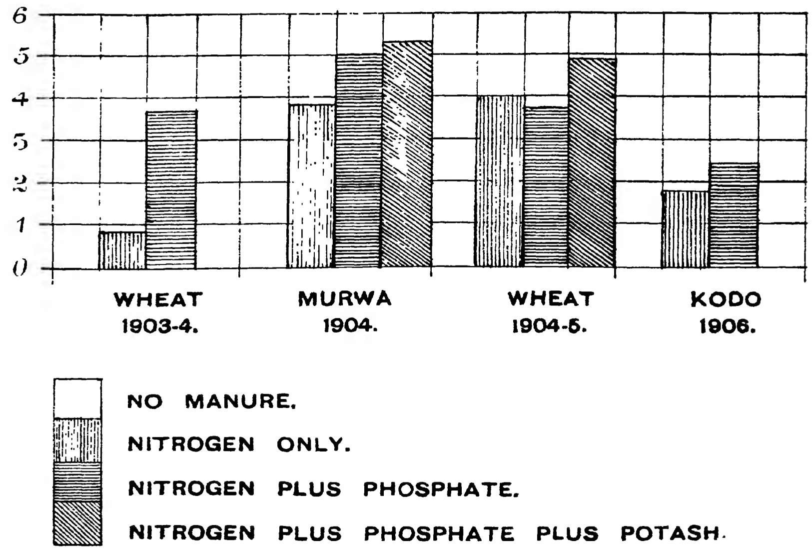


CHART No. 3.

PUSA SOIL.

RELATIVE WEIGHTS

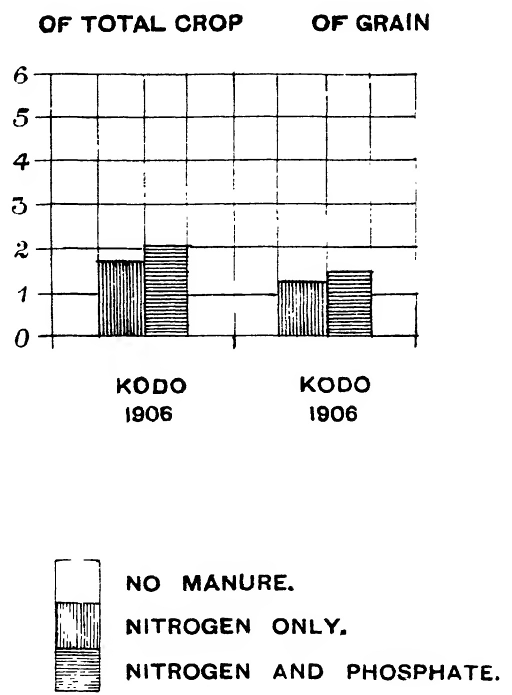


CHART No. 4.

BANGALORE SOIL.

RELATIVE WEIGHT OF TOTAL CROP

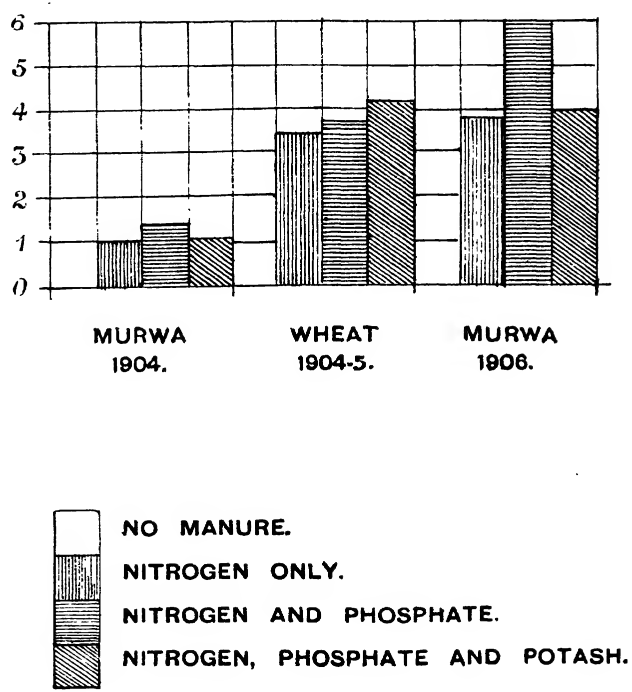


CHART No. 5.

SHILLONG SOILS.

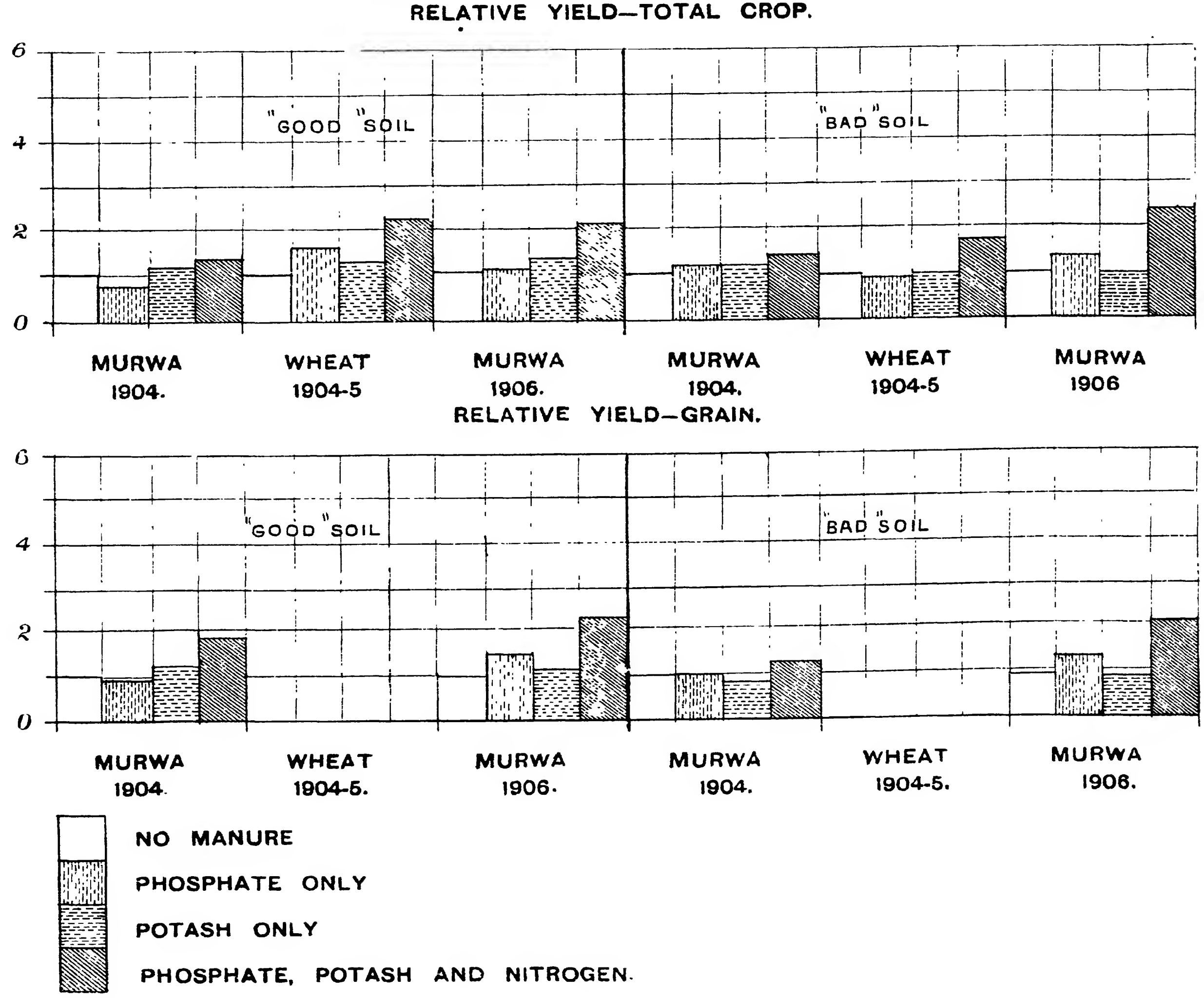
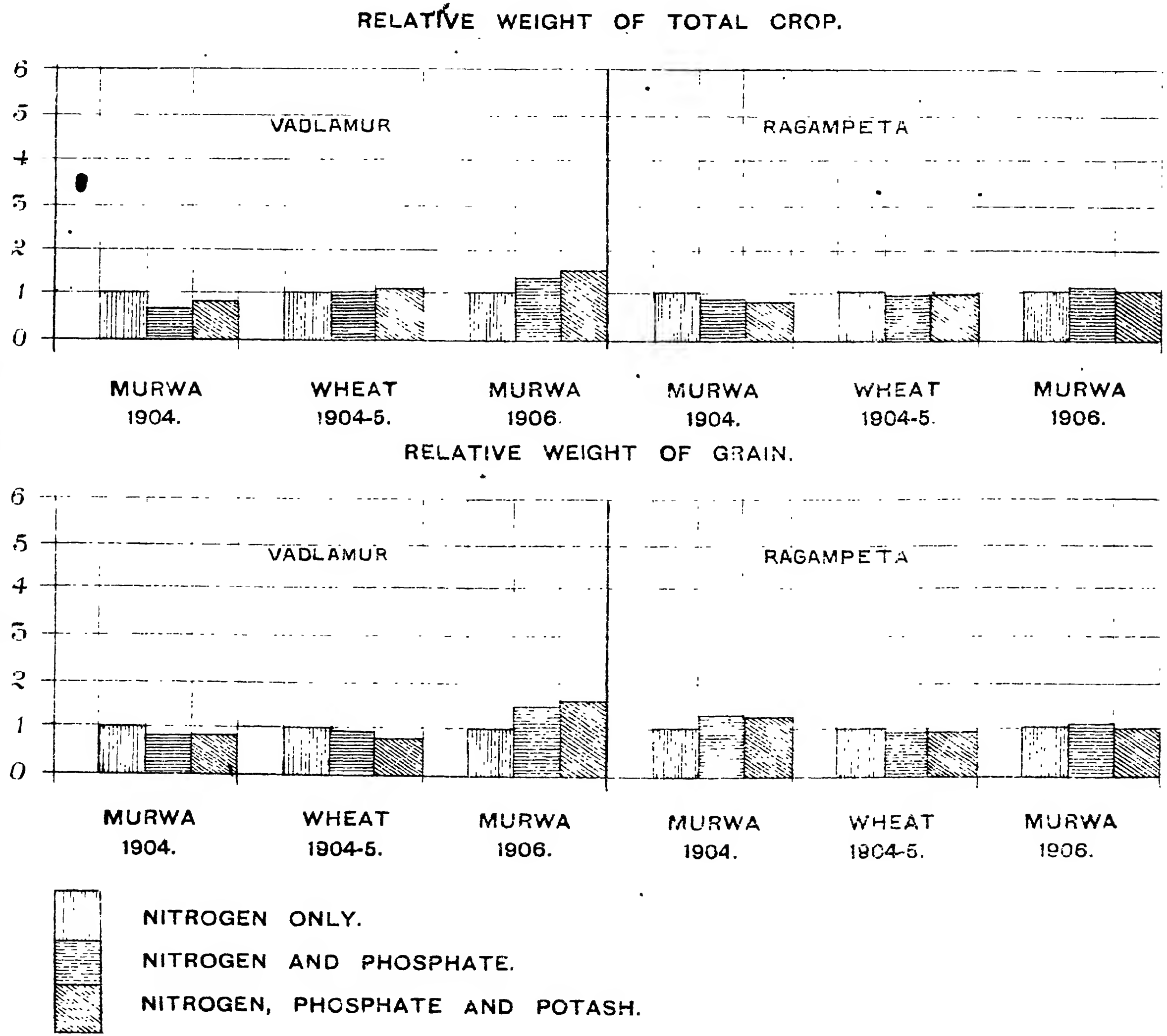


CHART No. 6.

GODAVERI SOILS.



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MEMOIRS OF THE DEPARTMENT OF AGRICULTURE IN INDIA

STUDIES IN THE CHEMISTRY AND PHYSIOLOGY OF THE LEAVES OF THE BETEL-VINE *(PIPER BETLE)*, AND OF THE COMMERCIAL BLEACHING OF BETEL-VINE LEAVES

BY

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THE use of the leaves of the betel-vine as a material for chewing is one of the peculiar practices of South Eastern Asia and especially of India, but in these countries it is nearly universal. Hence the plant is grown in almost every province of India, and grown under very special and peculiar conditions. The betel-vine, as is well known, is a creeper, grown always in intense shade,—the leaves being injured by exposure even for a short time to the sun,—with a continually moist atmosphere. These necessary conditions indicate that it must be, as it is, a very intensive cultivation, calling for the laying out of large capital to establish a '*pan*' (or betel-vine) garden, but one which yields, if successful, very large returns. The actual condi-

tions of cultivation have been often described,* and there is no need to repeat the description here.

It might have been anticipated that a product grown on such a large scale, and forming such a common article of consumption in India would have been the frequent subject of chemical investigation. This has, however, not been the case and with the exception of chemical enquiries made in Java, in Germany, and also in Western India† into the nature of the essential oil, very little has been done to elucidate the nature of the leaf or the causes which make it so highly valued. We have had the opportunity of investigating certain aspects of the chemistry and physiology of the leaves and betel-vine plants, and propose to consider the results which we have obtained up to date under the following heads :—

I. The occurrence of nitrates in betel-vine leaves, and plants, and their relationship to the growth of their vine.

II. The sugars, starch, tannin, essential oil and other normal constituents of the betel-vine and their relationship to the growth of the vine.

III. The commercial bleaching of the betel-vine leaf, and the chemical changes by which it is accompanied.

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* *Vide* Watt's Dictionary of the Economic Products of India, Article *Piper betle*. Also Agricultural Journal of India, Vol. IV, pp. 365—374; and Poona Agricultural College Magazine, Vol II, No. 2 : Vol. IV, No. 1.

† Kemp, quoted by Dymock, Warden & Hooper. Pharmacographica Indica. Part III, p. 188.

Schimmel & Co, Leipzig, Semi-annual Reports, 1887 (II, 31), 1888 (I, 8), 1889 (I, 6 : II, 6), 1890 (I, 6), 1891 (I, 5 : II, 5), 1893 (II, 4), 1907 (II, 13).

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I.

The Occurrence of Nitrates in Betel-vine Leaves and Plants, and their Relationship to the Growth of the Vine.

The occurrence of fairly large quantities of nitrates in the growing leaves of plants has hardly been known hitherto, and in the present case it was totally unsuspected. Our investigations simply, in fact, commenced with an attempt to ascertain the constituents, chiefly organic, which occur in the leaves and which are likely to play some part in the attractiveness of the leaves to an Indian palate.

A large quantity of *pan* (betel-vine) leaves, as they are bought in the bazar, was dried in the sun for two days, when they could be coarsely powdered by rubbing with the hands. This material was then successively extracted with Petroleum Ether (B.P. 35°-58° C.), Ether, Chloroform, Acetic Ether, and Alcohol. The percentages of the dry leaf extracted by these solvents were as follows :—

Solvent.	Extract. Per cent.
Petroleum Ether	3·33
Ether	1·16
Chloroform	1·27
Acetic Ether	·76
Alcohol	6·61
	13·13

Sixteen hundred grammes of the dried leaves were then extracted by continuous percolation with hot alcohol, the temperature being maintained constant at 65°C. by a water jacket. The extraction was continuous until the extract, at first dark green in colour, became colourless. This required about ten litres of alcohol.

On standing, this extract deposited a considerable quantity of crystals on the sides and bottom of the vessels in which the percolated liquid was received. The whole of the liquid was, therefore,

filtered, the crystals extracted with water, in which they proved to be soluble, and recrystallised. The amount thus obtained weighed 4·41 grammes or 0·26 per cent. of the original dried leaves.

Much to our surprise this crystalline substance obtained directly by the extraction of betel-vine leaves with alcohol, proved to be nothing else than Potassium Nitrate. By concentration of the filtrate from the first crop of crystals, and extraction of the residue with water, the actual amount of Potassium Nitrate obtained reached 11·9 grammes or 0·74 per cent. of the original dried leaves.

This was a totally unexpected result. Nitrates occur in minute quantities in many plant tissues, but there are hardly any cases where they exist in a proportion greater than 0·1 per cent. of the dried tissue, and it seemed important to ascertain how far the occurrence was a constant one.

Nitrates were therefore determined by direct estimation in the leaves by Schloesing's method. In order to do this it was only necessary to prepare a water extract of the leaves, and heat this, in the usual manner, in a current of carbon dioxide with ferrous chloride and sulphuric acid. The volume of nitric oxide evolved gives a direct measure of the amount of nitrate and nitrite present. This has been done in a large number of cases with leaves taken from various parts of the betel-vine. In the first series of determinations, three leaves were taken, on branches of the vine, from those nearest the main stem of the vine and from those which were furthest away. The results are shown in the table.

Date 1911.	Position of Leaves on Branch.	Dry matter.	Potassium Nitrate in Fresh Leaves.	Potassium Nitrate in Dry Leaves.
		Per cent.	Per cent.	Per cent.
May 22nd ...	......	......	·36	......
June 10th ..	Leaves furthest from vine ...	14·4	·37	2·62
June 10th ..	Leaves nearest vine ...	16·0	·42	2·66
June 17th ...	Leaves furthest from vine ..	12·8	·26	2·38
July 8th	Leaves furthest from vine .	12·8	·32	2·50
July 8th ...	Leaves nearest vine .	14·0	·36	2·56
July 22nd ...	Leaves furthest from vine ...	12·8	·30	2·32
July 22nd ..	Leaves nearest vine ...	14·4	·35	2·49

This table shows that the actual quantity of Potassium Nitrate in the leaves is higher than was apparent from our original extracts. Calculated from the nitric acid found by Schloesing's method on the fresh leaf the percentage naturally varies with the amount of moisture present in the leaves at that particular time,—but calculated on the dry matter, the amount seems fairly constant, and varies between 2·3 and 2·7 per cent. of the dry leaf.

The existence of this nitrate constantly in the leaves of the betel-vine at once raised the question as to what purpose it could serve, and the first steps to ascertain this could only be taken by ascertaining its distribution in the plant. With this object, determinations of nitrate were made, by Schloesing's method, from material taken from different parts of the vine plants.

1.—*Comparison of the branches and the leaves growing on them.*

No.	Branches. Potassium Nitrate in dry matter.	Leaves growing on the Branches. Potassium Nitrate in dry matter.
	Per cent.	Per cent.
1	2·55	2·01
2	2·13	1·74

These figures would indicate that the branches contain more nitrate than the leaves by about twenty-five per cent.

2.—*Comparison of the various leaves from the main vine stem.*

This comparison, as the following figures indicate, shows that the young tender leaves of the tips of the main vine contain a very small quantity of Nitrate, but as one proceeds further down the vine the percentage increases. Ten vines of nearly the same height were selected and the leaves growing on the main stem were sorted. The topmost four leaves were placed together for analysis, the next four together, and so on to the seventeenth leaf.

No.	Leaves.	Potassium Nitrate on dry leaf.
		Per cent.
1	Topmost four leaves	0·63
2	5th to 8th leaf from top	1·50
3	9th to 12th leaf from top	1·50
4	13th to 17th leaf from top	2·05

The leaves on the main vine are not much used for chewing.

3.—*Comparison of various branches, and of the leaves from these branches.*

Ten whole vines except the lowermost two feet were taken and divided into different parts. The two pairs of branches nearest the tip were placed together: then the third pair of branches: then the fourth and so on. In each case the leaves on these branches were examined for nitrate separately from the branches themselves. The following table shows the results:—

No.	Number of Branch (Counting from top.)	Leaves on Branch, Potassium Nitrate on dry matter.	Branches, Potassium Nitrate on dry matter.
		Per cent.	Per cent.
1	1st and 2nd branches	1·66	2·92
2	3rd branch	1·93	3·76
3	4th do.	2·13	3·74
4	5th do.	2·43	3·82
5	6th do.	2·22	3·76
6	7th do.	2·10	3·90
7	8th do.	2·31	3·93
8	9th do.	2·01	3·97
9	10th do.	2·50	3·26

This table shows clearly that the youngest leaves and branches do not contain so much nitrate as those which are more mature. Among the mature leaves and branches there is not much change in the quantity, but the branches (stems) always contain very much more nitrate than the leaves themselves.

4.—*Comparison between various portions of the main vines.*

The portions of the vine were taken so that the stem between each pair of branches formed a sample. Thus the topmost portion of the stem to the origin of the second pair of branches

formed one sample, that between the second and third pair formed a second, that between the third and the fourth a third and so on. The results of analysis are indicated in the following table :—

No.	Position of Vine.	Potassium Nitrate on dry leaf.
		Per cent.
1	Vine above the 2nd branches	4·46
2	Do. between 2nd & 3rd ,, ...	3·05
3	Do. do. 3rd & 4th ,, ...	2·04
4	Do. do. 4th & 5th ,, ...	2·00
5	Do. do. 5th & 6th ,, ...	2·19
6	Do. do. 6th & 7th ,, ...	2·01
7	Do do. 7th & 8th ,, ...	1·50
8	Do. do. 8th & 9th ,, ...	1·33
9	Do. do. 9th & 10th ,, ...	0·98
10	Do. below 10th ,, ...	0·72

These results are extremely curious. The younger stem contains far more nitrate than the lower portions, while *(vide comparison 2)* the leaves growing from these younger stems contain very little. To confirm the results, repetition of the examination of leaves from various parts of the main vine was undertaken.

5.—*Comparison of the various leaves from the main vine stem. (Repetition of comparison No. 2).*

No.	Leaves.	Potassium Nitrate (on dry leaf.)
1	Topmost four leaves	·68
2	5th to 8th leaf from top	1·66
3	9th to 12th leaf from top	1·94
4	13th to 16th leaf from top	2·01
5	17th to 20th leaf from top	2·04
6	21st to 24th leaf from top . ..	2·18
7	25th to 28th leaf from top	2·17

These figures confirm in every particular the former comparison.

The results brought out in these tables may be summarised as follows :—

(1) All parts of the living betel-vine plant contain nitrates.

(2) In the main stem, the amount of nitrate increases towards the growing tip.

(3) In the leaves on the main stem, on the contrary, the younger leaves contain by far the least amount of nitrate. As the leaves mature, they, however, very rapidly reach what may be called a normal amount.

(4) The youngest branches and the leaves growing thereon contain less nitrates than the mature ones. There is little difference between the various leaves and the various branches which have become mature.

(5) In general, the stems contain more nitrate than the leaves.

What then is the position of nitrate in the economy of the betel-vine plant? Of course, at the present stage it is impossible to do more than to put forward a few tentative suggestions, but it seems worth while to try and do this. In the first place it would seem that the nitrate in this case is absorbed direct from the root. Whether it is absorbed by the root, and transmitted without change, we do not know: on this point our figures give us no information. But it passes up the stems, and tends to concentrate in the upper part of the main stem. In the young and growing leaves and branches however, very rapid reduction of the nitrate takes place, and the quantity remaining is very small. The mature leaves seem to have very much less effect in reducing nitrates, though they have some. But the rapid reduction of the nitrates in the leaves and stems seems to be coincident with very active growth, such as occurs in young structures only. It might be hazarded that here we have, possibly, direct supply of nitrogen for growth to the leaves and shoots in the form of nitrates, and that in this case the reduction of the nitrate is done by the growing structure itself, instead of, as is usual, by the root of the plant. This is at any rate the direction to which our results lead, but a good deal more work will be required before this can be stated with confidence.

II.

The Sugar, Starch, Tannin and Essential Oil and other Normal Constituents of the Betel-Vine and their Relationship to the Growth of the Vine.

The original question which led to the present investigation was as to what is the cause of the use of the betel-vine leaf for chewing purposes. It was quickly found that no appreciable quantity of an alkaloid was present in the leaf, and no active glucoside seemed to be present. To what extent, then, are the other constituents normal, and to what extent do they differ in quantity in the various parts of the betel-vine plant. This was the question which we placed before ourselves, and we resolved to investigate the following normal constituents: (1) the tannin; (2) the sugars; (3) the starch; (4) the ether extract; (5) the essential oil; (6) the acidity; and (7) the diastatic activity. Put in this form, the inquiry has not proceeded very far, but the results we have obtained are at least suggestive.

The methods of estimation of these various constituents were as follows:—

(1) The sugars (reducing and non-reducing), and starch were determined almost exactly by the methods described by Brown and Morris in their account of their investigation of foliage leaves in 1893. In this the leaves are dried in an oven after placing them for a few minutes in chloroform vapour, or dipping them in alcohol—the latter by preference. The dried leaves are thoroughly powdered and extracted with ether to remove chlorophyll and fats. A definite weight is then taken for the starch determination (10 grammes). This quantity is placed in a flask and digested with alcohol of about 80 per cent. strength for 24 hours at 40° C. The alcohol is then poured off, and the extraction repeated. After the second extraction, the residue is repeatedly washed by decantation with warm alcohol, until the washings are free from colour. The residue from the alcohol treatment after drying is mixed with a little warm water, and

the mixture heated in a bath of boiling water to complete the gelatinisation of the starch. It is then cooled to 50° C., and malt extract is added (in which the sugar has been separately determined) and the conversion of the starch done for two hours at 50-55° C. The mixture is then raised to the boiling point, the solid matter removed by filtration and the cupric reducing power of the filtrate determined in the usual manner.

The original alcohol extract of the leaves, containing the sugars, is evaporated to dryness, after addition of a drop or two of ammonia to prevent possible inversion. The residue after addition of water is poured into a 100 cc. flask, 1 cc. of a strong solution of basic lead acetate added, and the whole made up to 100 cc. Basic lead acetate removes tannin and other matters which may interfere with sugar determination. The filtrate from the precipitate produced by the basic lead acetate is treated with sulphuretted hydrogen, filtered and washed, and then evaporated to remove sulphuretted hydrogen. The liquid contains the sugars from the original ten grammes of leaves. The reducing sugars are determined in the solution by Fehling's method volumetrically. The remaining solution is then treated with hydrochloric acid and kept on the water bath. After this the reducing power is again determined by Fehling's solution, and this gives a measure of the non-reducing sugars.

(2) The ether extract was determined by extracting the leaf dried *in vacuo* in a Soxhlet extractor in the usual way.

(3) The essential oil was determined by taking ten grammes of fresh leaves and distilling with steam from a separate vessel. The distillate obtained was shaken with ether five to six times. The ether extract was evaporated at the ordinary temperature, and the residue dried in a vaccum desiccator, and weights taken until it becomes constant.

(4) The tannin. Two grammes of dried leaves or eight to ten grammes of fresh leaves were extracted three times for half to one hour with one hundred cubic centimeters of boiling water. The extract was filtered hot each time. The various portions of the filtrate were brought to the boil and the tannin precipitated by

the addition of twenty to thirty cubic centimeters of copper acetate solution. The precipitate was filtered and the filtrate always appeared green with the excess of copper acetate. The precipitate was washed, dried and burnt in a porcelain crucible. After cooling a little nitric acid is added and all the copper converted into cupric oxide by heating. The residue is copper oxide and one gramme of this is taken as equivalent of 1·306 grammes of tannin.

(5) In estimating the acidity one hundred grammes of the fresh leaves were taken, and soaked in 500 cc. of cold water for twenty hours. The acidity of the liquid was then determined by decinormal solution of caustic potash, using phenol phthalein as indicator.

(6) The diastatic activity was estimated precisely by the method devised by Brown and Morris in 1893 (*loc. cit.*). This is as follows :—Half a gramme of the finely powdered air dried leaf was digested at 30° C. with 50 cc. of a 2 per cent. solution of soluble starch which had been previously prepared by the limited action of hydrochloric acid on starch according to the method of Lintner. The digestion of the mixture was carried on for exactly forty-eight hours, the danger of any appearance of micro-organisms being averted by employing chloroform at the rate 5 cc. per litre of starch solution. A duplicate experiment was made by taking the same amount of leaf and starch solution, boiling the mixture for a minute or two and placing alongside the first solution. This solution was used for correcting the first solution for cupric reducing power of the sugars naturally contained in the leaf.

The difference between the cupric reducing powers of the first and second solutions was a measure of the hydrolytic work done and it became possible when the time and all other conditions remain constant to compare the relative diastatic activities in this way.

The cupric reduction was calculated in all cases as maltose and for purposes of comparison this was referred to one hundred grammes of the dry leaf so that the numbers indicating the relative diastatic activity really represent the number of grammes of maltose which the diastase of one hundred grammes of leaf is

able to produce from soluble starch by hydrolysis in forty-eight hours at a temperature of 30°C.

A number of betel-vine plants were taken and stripped of leaves at the same time, the leaves being divided into several lots, as follows :—

Leaves from the main vine—

(1) Leaves from the topmost two feet of the main vine.

(2) Leaves from two to four feet from the top of the main vine.

(3) Leaves from four to six feet from the top of the main vine.

Leaves from the branches—

(1) Leaves from all branches whose origin is within two feet of the top of the vine.

(2) Leaves from all branches whose origin is from two to four feet from the top of the vine.

(3) Leaves from all branches whose origin is from four to six feet from the top of the vine.

The vines used were not completely grown, their height being on the average, about nine feet. There are seldom any branches or leaves within three feet of the ground, and so the analyses made included practically leaves from all parts of the vine.

All the samples were taken at one time in the morning (10 A.M.).

The results are indicated in the following series of tables. All percentages (except where otherwise indicated) are on the dry leaves :—

1. *Sugars*—

	Reducing sugars (as glucose).	Non-reducing sugars (as saccharose).	Total sugars.
I. Leaves from the main vine—	Per cent.	Per cent.	Per cent.
(1) Within two feet of tip ...	1·60	1·20	2·80
(2) 2 to 4 feet from tip	1·41	1·31	2·72
(3) 4 to 6 feet from tip	1·55	1·18	2·73
II. Leaves from branches—			
(1) Within 2 feet of tip of main vine ...	3·17	2·48	5·65
(2) 2 to 4 feet from tip of main vine ...	2·26	1·12	3·38
(3) 4 to 6 feet from tip of main vine ...	1·86	·59	2·45

So far as the leaves on the main vine are concerned, the amount of both reducing and non-reducing sugars is very constant. But when the results from the branches are taken, there is a very marked difference. On the whole, the total amout of sugars in the leaves on the branches is higher than in those on the main stem, except with regard to the branches on the lower part of the vine, where the non-reducing sugars are very low indeed. But among the branches themselves, there is a very large difference. The upper branches that is to say the younger branches bear leaves with a very large sugar content, both reducing and non-reducing. This amount declines regularly as one proceeds lower and lower in the branches originating lower and lower in the creeper. The decline is proportionately greater in the non-reducing sugars than in the reducing sugars as the following figures indicate :—

	Reducing sugars.	Non-reducing sugars.
	Per cent.	Per cent.
1. Leaves on middle branches contain less than those on the topmost branches by	28·7	54·8
2. Leaves on lower branches contain less than those on the topmost branches by	41·3	76·2

The meaning of this can best be discussed, perhaps, in connection with the figures for the percentage of starch.

2. *Starch*—

	Starch.
	Per cent.
I. Leaves from the main vine—	
1. Within two feet of tip	1·1
2. 2 to 4 feet from tip	1·1
3. 4 to 6 feet from tip	1·0
II. Leaves from branches—	
1. Within two feet of tip of main vine	1·2
2. 2 to 4 feet from tip of main vine	1·2
3. 4 to 6 feet from tip of main vine	1·2

Here we have an extraordinary constancy. The amount of starch hardly varies at all between the leaves in the main vine,

and those on the branches,—and also between the leaves on the upper and lower parts of the vine,—when, it is understood, the leaves are collected in the morning.

If we take these figures with those which have already been given for the sugars, they would simply seem to indicate that the physiological processes of metabolism are much more active in the younger leaves near the top of the plant than in the lower part. In both cases the starch is small in amount, as would be expected in the morning. The relationship between the reducing and non-reducing sugars in leaves from branches in different parts of the vine seems significant of much more than this. On the branches from the upper part of the plants the non-reducing sugars in the leaves are 78·2 per cent. of the reducing sugars : on the middle branches the non-reducing sugars in the leaves are 49·8 per cent. only of the reducing sugars : on the lower branches, the non-reducing sugars are 31·7 per cent. only of the reducing sugars In other words where absorption and metabolism are most vigorous, in the early morning the non-reducing sugars are very large in proportion to the reducing sugars. This would seem to be, on the whole, evidence that non-reducing sugar (say saccharose) is a first product of carbon dioxide absorption.

3. *Ether Extract*—
4. *Essential Oil*—

	Ether Extract.	Essential Oil.
I. Leaves from the main vine—	Per cent.	Per cent.
1. Within two feet of tip ...	8·0	1·6
2. 2 to 4 feet from tip ...	8·5	1·2
3. 4 to 6 feet from tip ...	8·1	1·1
II. Leaves from the branches—		
1. Within 2 feet of tip of main vine ...	7·5	1·8
2. 2 to 4 feet from tip of main vine ...	7·6	1·0
3. 4 to 6 feet from tip of main vine ...	8·4	·8

There is little to be remarked about the figures obtained for ether extract, nor would it be expected that anything of importance would become clear from an estimation of the

heterogenous mass of substances extracted by ether. The determination of essential oil gives results, however, of decided interest. The leaves from the upper part of the plant, in each case contain more essential oil than those in the lower part of the plant. This is particularly marked in the leaves on the branches. While the leaves at the bottom of the main stem contain 70 per cent. of the essential oil in those near the top, the leaves on the lower branches only contain 44 per cent. of those on the branches near the top. The gradual diminution of essential oil as one goes down the plant is interesting in view of the fact that young leaves near the top of the plant are not considered good for chewing, though (as we shall see later), it is undoubtedly the essential oil which gives the leaves their chief value. There is evidently some other constituent or condition in the younger leaves which neutralises the effect of the larger amount of essential oil. What this is, we have no information at present.

5. *Tannin*—

When these investigations were commenced, we had an idea that the astringency of the leaves had something to do with their value, and hence the estimation of that class of substances which may be taken together as 'tannin' was of very considerable interest. The figures obtained were, however, as follows :—

	Tannin.
	Per cent.
I. Leaves from the main vine—	
(1) Within two feet of tip	·97
(2) 2 to 4 feet from tip	1·24
(3) 4 to 6 feet from tip	1·17
II. Leaves from the branches—	
(1) Within 2 feet of tip of main vine	1·05
(2) 2 to 4 feet from tip of main vine	1·30
(3) 4 to 6 feet from tip of main vine	1·11

The figures obtained do not show much variation in the amount of tannin in the different parts of the plant. But both the leaves from the main vine, and those from the branches do seem to indicate that the largest percentage of tannin sub-

stances are contained in the leaves from the middle of the plant. The younger leaves do not appear to have acquired their maximum amount: the older ones seem to have lost some of what they once possessed.* This is curious from the fact that it is precisely these middle leaves which are most desired for chewing. The matter is one which demands further investigation, but, so far, we have not been able to spare time for it.

6. *Acidity*—

The acidity found in the leaf did not vary very much according to the part of the plant from which the leaf was taken. The actual figures reported represent the number of cubic centimetres of caustic potash solution of "one-tenth normal" strength required to neutralise the acidity of the leaf. They are as follows:—

	Acidity. (Cubic centimetres of $\frac{N}{10}$ caustic potash required for 100 grammes dry leaf).
I. Leaves from the main vine—	
(1) Within two feet of tip	56 cc.
(2) 2 to 4 feet from tip	60 cc.
(3) 4 to 6 feet from tip	58 cc.
II. Leaves from the branches—	
(1) Within 2 feet of the tip of the main vine	56 cc.
(2) 2 to 4 feet from tip of main vine	62 cc.
(3) 4 to 6 feet from tip of main vine	60 cc.

7. *Diastatic Activity*—

The figures which follow, indicate the number of grammes of starch which will be converted into maltose by 100 grammes of the dried leaf in forty-eight hours. It will easily be seen that this figure may be of importance in view of the general reputation of betel-vine leaves as a digestive agent. The actual figures

* These results are interesting when compared with those obtained for tea, the only other plant we know which has been investigated in this sense. In that plant the youngest leaves contain far the largest quantity of tannin substances.

are as follows, the leaves being gathered in the morning, about 10 A.M.

	Diastatic Activity.
I. Leaves from the main vine.	
(1) Within 2 feet of tip	12·8
(2) 2 to 4 feet from tip	12·1
(3) 4 to 6 feet from tip	4·5
II. Leaves from the branches.	
(1) Within 2 feet of tip of main vine	14·3
(2) 2 to 4 feet from tip of main vine	8·5
(3) 4 to 6 feet from tip of main vine	7·0

It is difficult to see a relationship between the use for chewing and the diastatic activity. The lower, harder, and older leaves naturally contain less diastase, and are recognised as unsuitable for use. The middle leaves are the best for chewing,—better than the younger leaves on the plant. This does not seem to correspond in any way with the diastatic activity. The diastase is far more variable than the amount of starch on which it acts.

Such are the general characters of the leaves obtained from different parts of the betel-vine at the same time. The younger leaves on the plant contain much more essential oil, much more diastase, and much more sugars than those which are older. On the other hand the tannin does not vary in this direction. The leaves both on the middle branches and on the middle part of the main vine contain slightly the largest quantity of 'tannin.' To go further than this in regard to the causes of the universal use of betel-vine leaves and the reason for which they are eaten demands a comparison of leaves more or less highly appreciated. The study of the production of the so-called 'bleached' leaves, which are about three times the value of ordinary green leaves, promised to give results in clearing up this question. Their study was, therefore, taken up in considerable detail.

III.

The Commercial Bleaching of the Betel-Vine Leaf, and the Chemical changes by which it is accompanied.

It is well known that although the leaves of the betel-vine are eaten in their fresh condition in by far the majority of cases, yet this is not the state in which they are most appreciated, at any rate in Western India. When required for special occasions or by those who can pay the extra price demanded, they are used in the bleached condition. That is to say, they are prepared in such a fashion that the larger part of the chlorophyll apparently disappears, the leaves become quite tough but flaccid, and they appear almost of the colour of leaves etiolated by being grown in the absence of light.

This process of bleaching betel-vine leaves has never, so far as we can find, been the subject of any investigation. That storehouse of information, Watt's Dictionary of the Economic Products of India, although it devotes seven pages * to the description of the leaves of the betel-vine, their preparation and their uses, does not even mention the fact that they are bleached. The same is the case also with the same author's more recent book on the Commercial Products of India, † and other authors are equally silent. And yet the process is the basis of a very considerable industry carried on by a special class of people who keep their processes secret with very great care. Most of the people, at least in the neighbourhood of Poona, are Mohamedans called *Tâmboli* or more commonly *pan-bhatiwalas.*

The result of bleaching is a very great increase in the value of the leaves. The actual price paid for leaves of various kinds in the Poona bazaar for a number of months has been ascertained and is given in the table opposite.

We have had the advantage of being allowed by one of the members of this community to follow his system carefully, and are hence able to present here the actual methods which he

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* Vol. VI, Part I, page 247.

† Pages 891—896.

Price per 1,000 leaves.

	April.	May.	June.	July.	August.	September.	October.	November.	December.	January.
(1) Ordinary green leaves not used for bleaching.	8 as. to 10 as.	10 as. to 15 as.	10 as. to 15 as.	12 as. to Re. 1.	5 as. to 6 as.	6 as. to 8 as.	6 as. to 8 as.	6 as. to 8 as.	8 as. to 10 as.	8 as. to 10 as.
(2) Fresh green leaves fit for bleaching.	Re. 1 to Re. 1-4.	Re. 1-4 to Re. 1-8.	Re. 1-4 to Re. 1-8.	Re. 1-4 to Re. 1-8.	6 as. to 8 as.	10 as. to Re. 1.	10 as. to Re. 1.	10 as. to 12 as.	10 as. to 12 as.	10 as. to 12 as.
(3) Ordinary bleached leaves containing yellow, white, half bleached, etc.	Re. 1-4 to Re. 1-8.	Re. 1-8 to Rs. 2-4.	Rs. 2 to Rs. 2-8.	Rs. 2 to Rs. 2-8.	10 as. to 12 as.	12 as. to Re. 1-4.	10 as. to Re. 1.	Re. 1 to Re. 1-4.	Re. 1 to Re. 1-8.	Re. 1 to Re. 1-8.
(4) Best bleached leaves—white and of good shape.	Re. 1-8 to Rs. 2.	Rs. 2 to Rs. 2-12.	Rs. 2-12 to Rs. 3-8.	Rs. 3 to Rs. 4.	Re. 1 to Re. 1-4.	Re. 1-4 to Re. 1-12	Re. 1-4 to Re. 1-12.	Re. 1-8 to Re. 1-12.	Not available in large amount.	Not available.

employs. We have also followed the process by analysis with reference to several of the important constituents, and are able to give in addition an account of the variation in these constituents throughout the process.

The leaves of the betel-vine to be used for bleaching should best be obtained from a garden of at least three years' standing, and the best results are obtained with leaves from a garden four to seven years old. This ensures that the vines are of older growth and the leaves well developed. These leaves should not be very tender, or inferior results are obtained. In buying the leaves for bleaching,—for the bleachers are always different people from the growers,—attention should be paid to the colour, especially in the case of leaves from vines which have been recently earthed up, and new growth produced (*navati* leaves). The colour should be a dark green, rather darker than usual, and not on any account a light green or *gajrya*. These light coloured leaves are useless as they often rot during the bleaching process. The midrib should be prominent and the stalk and surface of the leaves should be rather rough to the touch. These are of course the practical tests, but the eye of experience is quite sufficient to detect a good lot of leaves for the purpose.

Not only, according to the growers, is the actual character of the leaves important, but the season in which they are taken. In the cold weather, and especially in the months of November, December, and part of January the growth of the leaves is very slow and they give poor results when they are bleached. During this season the leaves rot rather than bleach. The commencement of the hot weather gives the best results. From the end of March to May the coiling of the creepers takes place, and at that time the most suitable leaves (*jununvan*) are available in smaller quantities and are very dear. In fact, all leaves are more scarce at this time of year than at any other. From May onward the new leaves (*navati*) begin to appear in the market. These are useless for bleaching until they become dark in colour with increasing age. Then they improve in quality. By July

they can be used for the purpose, and from August and onward they are quite in good condition like the *junawan*.

The method of bleaching is as follows: One *kudtan*, or from fifty to seventy pounds of leaf is bleached at one time. This *kudtan* contains forty-one *karalis*, each containing four hundred leaves, so that a *kudtan* contains about 16,400 leaves. The packing of the leaves in the *kudtan* is peculiar, but quite systematic, and is exactly similar to that used in packing betel leaves for transit. The stalks of the leaves should be cut close to the base of the leaf. A special instrument is used for this purpose but scissors answer the same purpose.

A large round basket from two to two and a half feet in diameter and twelve to eighteen inches high is selected and lined with matting. If a smaller number of leaves are to be bleached at once the height should be greater and the diameter less. There is nothing special in the form or material of the basket and a galvanised iron pot is often used. In this case, though the process is more rapid, a larger proportion of the leaves become rotten. In this case plantain leaves are spread at the sides and bottom of the vessel.

Usually after lining the basket with matting and a few plantain leaves inside this, water is sprinkled to wet these leaves. Then betel leaves with stalks duly cut off are arranged in layers, the leaves being almost vertical, but lying slightly over one another, the underside uppermost, as in the ordinary packing of such leaves for transit. Each layer is in the form of two or three circular rings of leaves. A vertical hole is reserved in the centre of convenient diameter to allow the hand when introduced to reach the bottom layer easily. This enables a constant watch to be kept over the process. The leaves in each layer usually amount to two thousand five hundred. After each layer is complete one to two pounds of water is sprinkled carefully over all the leaves in the layer. In all ten to twelve pounds of water or fifteen pounds at the utmost are sprinkled over one *kudtan* of leaves,—at least, this is the quantity in the hot weather. In the rainy season the amount used is less, as the

leaves then are more watery, and reaches five to ten pounds in all. Experience, however, is said to be the only guide as to the exact amount to use: the larger the amount of water used, the more rapid is the bleaching. In this case, however, there is much more rotting among the leaves, and a slow bleaching is always preferred. These quantities apply to *junawan* leaves: *narati* leaves require less water. Any excess of water gradually drains away.

There are several other methods of wetting the leaves, and the manner in which it is done is evidently a matter of detail. Sprinkling, however, is considered best, as leading to a slow, normal bleaching, with very few rotten leaves.

The basket is then covered with a wet gunny bag and kept in a warm, ventilated place,—where there is no chance of sunshine. In this state the basket should be kept for three or four days according to season. On the third or fourth day the gunny bag is removed and the state of the leaves observed. They are examined to see whether the water added is sufficient or in excess, as also to note whether there has been any sudden rise in temperature. After about eight days all the leaves are taken out, carefully examined and any which have commenced to rot removed. If the colour of the leaf near the base becomes red or reddish brown, it should at once be rejected. A yellow colour or a turmeric colour anywhere on the leaf is very objectionable. Leaves with clear spots of this colour are also removed.*

At this stage there are a few leaves which have bleached properly and these are taken out for use, and the remainder arranged in the *kudtan* as before. No more water is now added, but the plantain leaves at the bottom are again wetted. The whole mass may now be weighed and covered by a wet gunny bag as usual.

The taking out and picking over is repeated every five or six days, and at every stage more leaves are bleached. If a longer time is allowed to elapse, a large number quickly become rotten.

* This objectionable colour is classed as Indian yellow (*Jaune indien*) in the colour scale published by the Société francaises des chrysanthemistes and prepared by R. Oberthür.

In the hot weather almost all that are likely to give good results have bleached in ten to twelve or fifteen days ; in the cold weather they are kept for fifteen to twenty days, or even longer than this,—and yellow rather than white leaves are usually obtained.

The process of selecting and turning the leaves is considered extremely important as after the first few days more and more of the leaves begin to rot, and this rotting quickly spreads to the other leaves. If it is required, by continuous turning a large proportion of the leaves can be kept good for two months.

The colour to be desired in the final product is that termed *jaune soleil* or sunflower yellow in the colour scale previously referred to. Highly bleached leaves sometimes reached an *amber white* (*blanc ambre*) on the same colour scale. Properly bleached leaves should be very soft, tender, of the proper colour, but very bright, clear of any stain as if rotting had commenced, and they should further increase in brightness on keeping. A brittle leaf is not liked, and leaves too highly bleached are objected to.

The following is an account of an actual experimental bleaching under our observation.

The *bhati* was set on June 11th, 1911.

The first turning out and selection took place on June 16th, 1911. The leaves which showed an Indian yellow colour were thrown aside for use at once. They are called 'dead' and are utterly useless for further keeping. The rotted ones were thrown out as well as those which had begun to turn brown at the base. Those which had begun to turn brown at the tapering end were kept after removing the rotted part. Nearly ten per cent. of the leaves became useless for further bleaching. Practically no leaves showed any sign of real bleaching. Among *navati* leaves, there was no change at all except a duller appearance.

The second, third, and fourth turnings which followed every fifth or sixth day were carried out in the same way. No further water was applied except the wetting of the plantain leaves at the bottom of the basket, and of the gunny bag with which the *kudtan* was covered. The basket was kept in a cool place. The

colour showed progressive changes from the fresh green of the original leaves to a fully bleached colour.

On the fifteenth day all the leaves were bleached, except those which had become rotten or were considered as unlikely to bleach if kept further.

This was the process as carried out by the *Tamboli* and it seemed so simple that the next step was to carry out the bleaching ourselves under conditions where the control could be more perfect and the process could be watched with greater care. Leaves were therefore brought from a *pan* garden packed in the ordinary *kudtan*. The leaves contained in the *kudtan* and few others after removal of the stalks weighed twenty-three kilogrammes about, while the stalks removed weighed six kilogrammes. The number of leaves was approximately sixteen thousand.

The *bhati* was started on November 1st, 1911, in a basket of the form ordinarily used for this purpose. It was lined with plantain (*vawali*) leaves as usual at the bottom of the basket. Two pounds of water were required to moisten these.

The leaves were then arranged in the usual way, packed almost vertically side ways, but slightly leaning over so that the lower side of the leaf faced uppermost. One pound of water was sprinkled over each layer and thus five pounds for the whole *bhati* of leaves. The whole was then covered by a wet gunny bag in the approved style to stop evaporation and, as the people say, to maintain the temperature of the *bhati* as far as possible. The leaves when taken for the bleaching process were not dry as the *kudtan* containing leaves had been a short time previously soaked in water and hence very little water was required. The leaves were in excellent condition for bleaching. Four days later the leaves were all examined and repacked, not this time so much to pick out the bleached leaves as to see whether the water added was sufficient or in excess and also to see if there had been a sudden rise in temperature.

This examination is stated to be necessary for if the water added be too large in amount, the temperature rises, the leaves

become dark in colour, rot quickly and do not bleach well. If the amount of water is too small, the bleaching is uneven and the leaves are apt to dry, which is fatal. In the present case the leaves were rather dry and four pounds of water additional were added to the *bhati*. There was no change in the colour of the leaves and no great increase in temperature.

On November 10th—ten days after the leaves were put to bleach—they were turned for the first time in order to remove the leaves wholly or partially rotten and others which were useless for further keeping, as well as any which may be already bleached. The following were the actual figures obtained :—

November 1st, 1911.

Total Weight		... 23,080 grammes.

November 4th, 1911.

Total Weight		... 22,100 „
Leaves removed rotting	... 180 grammes.	
Weight of leaves remaining	... 22,220 „	

November 10th, 1911.

Total Weight		... 21,820 „
Leaves bleached and fit for use	... 1,130 grammes.	
Leaves partially bleached	... 1,540 „	
Leaves not yet bleached	... 13,560 „	
Partly or wholly rotten and hence removed ...	... 2,190 „	

The extent to which the decay had gone in the leaves removed rotting, was as follows :—

Leaves rotten throughout	... 30 grammes.
Leaves rotten at the tip only	... 1,750 „
Leaves rotten at the stalk only	... 167 „
Leaves, not rotten, but showing signs of incipient decay	... 543 „

In rearranging the leaves the whole of the rotten and of the bleached leaves were removed and samples amounting respectively to 500 grammes of unbleached leaves and 906 grammes o partially bleached leaves were taken, and, as is usual, the layers which had previously been uppermost were put at the bottom. The total weight of leaves placed in the *kudtan* again was 16·78

kilos. As the temperature was low, the leaves were not again examined, turned and repacked until November 16th. This second turning with the third is supposed to give the best bleached leaves. The actual figures obtained of the second turning, *i.e.*, on November 16th are given below :—

November 16th, 1911.

Total Weight		... 15,770 grammes.
Leaves bleached and fit for use ...	3,920 grammes.	
Leaves not yet fully bleached and fit for further keeping ...	9,320 ,,	
Leaves partially or wholly rotten	2,530 ,,	

The extent to which the decay had gone in the leaves removed as rotting was as follows :

Leaves rotten throughout ...	223 grammes.
Leaves rotten at the tip only ...	1,242 ,,
Leaves rotten at the stalk only ...	680 ,,
Leaves not rotten, but showing signs of incipient decay ...	380 ,,

In again rearranging the leaves the whole of the rotten leaves and of the bleached leaves were removed, and a sample amounting to 1,950 grammes of the unbleached leaves was taken out for examination. The total weight of leaves replaced in the *kudtan* was 7,370 grammes. The next examination took place on November 21st, 1911, and resulted as follows :—

November 21st, 1911.

Total Weight		... 6,750 grammes.
Leaves bleached and fit for use ...	3,200 grammes.	
Leaves not yet fully bleached, and fit for further keeping ...	2,400 ,,	
Leaves partially or wholly rotten	1,150 ,,	

The extent to which the decay had gone in the leaves removed as rotting was as follows :—

Leaves rotten throughout ...	200 grammes.
Leaves rotten at the tip only ...	500 ,,
Leaves rotten at the stalk only ...	450 ,,

In arranging again the small quantity of leaves for further bleaching, care had specially to be taken to avoid the possibility

of drying. The total weight of leaves replaced in the *kudtan* was 2,700 grammes. They were again examined on November 30th, as follows :—

November 30th, 1911.

Total Weight		2,590 grammes.
Leaves bleached and fit for use ...	1,170 grammes.	
Leaves not bleached and fit for further bleaching	360 ,,	
Leaves partially or wholly rotten	1,060 ,,	

The extent to which the decay had gone in the leaves removed as rotting was as follows :—

Leaves rotten throughout ...	410 grammes.
Leaves rotten at the tip only ...	130 ,,
Leaves rotten at the stalk only ...	520 ,,

This was the end of the process. The leaves which refuse to bleach can be sold cheaply as fresh leaves. Those which have rotten patches at the tip or the stalk have the rotten pieces removed, and are then sold as leaves of inferior quality.

The total result of this commercial bleaching of betel-vine leaves was as follows :—

Original weight of leaves	23,580 grammes.
(Leaves taken for samples	4,520 ,,)
	19,060 ,,
Actual weight of leaves obtained	16,210 ,,
Leaves bleached and fit for use	8,630 grammes.
Leaves which did not bleach	360 ,,
Leaves partly or wholly rotten	7,227 ,,
Actual loss in weight during bleaching ...	2,850 ,,
	19,067 ,,

The extent, taking the whole operation into account, to which the decay had gone in the leaves when removed was as follows :—

Leaves rotten throughout	865 grammes.
Leaves rotten at the tip only	3,622 ,,
Leaves rotten at the stalk only	1,817 ,,
Leaves removed as showing incipient rotting ...	923 ,,
	7,227 ,,

Of these all except the first would be saleable.

Temperature of Bhati

(taken at 1 p.m. daily).

	1st November, 1911.	2nd November, 1911.	3rd November, 1911.	4th Examination day. New arrangement of leaves.	5th.	6th.	7th.	8th.	9th.	10th Turning day. New arrangement.	11th.	12th.	13th.	14th.	15th.	16th Turning day.	17th.	18th.	19th.	20th.	21st.	22nd.	23rd.	24th.	25th.	26th.	27th.	28th.	29th.	30th.
Room Temperature ..	28°C	28°	28·2°	26·2° morning 28·2 noon	28°	28	28°	28	27·5°	27	27°	27	27°	27	28°	28°	27·5°	27°	27°	27·2°	27°	27°	26·5°	26°	25°	26°	25·5°	26°	26°	26°
Upper layer ...	27°	27°	27·5°	26·2°	26·5°	27°	27	28°	27	27	25°	26°	26°	26	27°	26·5°	24	24°	24·5°	24·5°	25°	25°	25°	25°	25°	25°	25°	25°	25°	25°
Middle layer ...	28°	29°	28·5°	28·2°	28°	28·2°	28·5°	29°	28·5°	28·6	26°	27°	27·5	27·5	27·5	27·5	25°	25°	25·5°	25·5°	25·5°	25°	26°	25°	25°	25°	25°	25	25°	25°
Bottom layer ...	28	28·5°	28°	28°	28°	28°	28°	28°	27·5°	27·5°	25°	26°	26·5	26·5	27°	26°	25	25°	25°	25°	25°	25°	25·5°	24·5°	24°	24°	24°	24°	24°	24°
Central hole at the top ...	..	27	26°	26°	25·5°	26·5	26°	27°	27	27°	25°	25°	26°	25°	26·5°	26°	25	25°	25°	25°	25°	25°	25°	25°	25°	25°	25°	25°	25°	25°
Central hole at the middle ...	..	27°	26·5°	26·5	26°	27°	27°	28°	27·5°	27·5°	25°	25·5°	26°	25·5°	27°	26·5°	25	25°	25°	25°	25°	25°	25°	24°	24°	24°	24°	24°	24°	24°
Central hole at the bottom ...	..	27°	26°	26°	26°	26·5	26·5°	27°	27°	27	25°	25°	25°	25·5	27	26°	25°	25°	25	25°	25°	25°	24·5°	24°	24°	24°	24°	24°	24°	24°

March 9th, 1912. The progress is shown by the following figures :—

March 9th, 1912.

Total weight		27,820	grammes.

March 11th, 1912.

Total weight		27,670	grammes.
Leaves showing signs of incipient rotting and hence removed	670 grammes.		
Weight of leaves remaining ...	27,000 ,,		

March 15th, 1912.

Total weight		22,680	,,
Leaves bleached and fit for use ...	570 grammes.		
Leaves not bleached or partly bleached	18,710 ,,		
Partly or wholly rotten	3,400 ,,		
Total weight of leaves retained after turning* ...		17,680	,,

March 21st, 1912.

Total weight		16,230	,,
Leaves bleached and fit for use ...	3,500 grammes.		
Leaves not bleached and fit for further bleaching	12,070 ,,		
Partly or wholly rotten	660 ,,		
Total weight of leaves retained after turning ..	9,980 ,,		

March 29th, 1912.

Total weight	8,650 ,,
Leaves bleached and fit for use ...	5,000 ,,
Leaves not bleached or fit for further bleaching	2,150 ,,
Partly or wholly rotten	1,500 ,,

The total result of this commercial bleaching of this lot of betel-vine leaves was as follows :—

Original weight of leaves	27,820	grammes.
(Leaves taken for samples	3,420	,,)
	24,400	,,
Actual weight of leaves obtained	17,450	,,
Leaves bleached and fit for use ...	9,070	grammes.
Leaves which were not bleached ..	2,150	,,
Leaves partly or wholly rotten ...	6,230	,,
Actual loss of weight during bleaching ...	6,950	,,
	24,400	,,

* Large samples were taken from the leaves for analyses at each turning, and hence there appears to be a very large loss.

Temperature Chart of Pan Bhati

(taken at 1 p.m. each day).

	9th March 1912.	10th.	11th.	12th.	13th.	14th.	15th Turning day	16th.	17th.	18th.	19th.	20th.	21st Turning day.	22nd.	23rd.	24th.	25th.	26th.	27th.	28th.	29th.
Room temperature ...	26	26°	27°	27°	28°	28°	28°	27°	28°	28·5°	29°	30°	30°	31°	30°	31°	31°	31°	31°	30°	30°
Temperature below upper layer.	25°	25	27°	29°	30°	31°	31°	26°	26°	26	26·5°	27°	27°	26·5°	26°	26°	27°	27°	27°	27°	27°
Temperature in the middle	25°	25°	28°	31°	33°	33°	33	26°	26·5°	26·5°	27°	28°	28°	27·5°	26°	27°	28°	28°	28°	28°	27°
Temperature at the bottom.	25°	25°	28°	30°	31°	32°	32°	25°	26°	26°	27°	28°	28°	28°	26°	26°	28°	28°	28°	28°	28°
Temperature in the hole .	25°	25°	27°	29°	30°	32°	32°	26°	26°	26°	26·5°	27°	27°	27°	26°	26	27°	27°	27°	27°	27°

In this case there was a distinct rise of temperature in the *bhati* in the early part of the process only; afterwards the temperature remained almost constant throughout, and certainly not higher than that of the room where the operation was done.

The extent, taking the whole operation into account, to which the decay had gone in the leaves when removed was as follows:—

Leaves rotten throughout	554	grammes.
Leaves rotten at the tip only	3,042	,,
Leaves rotten at the stalk only	540	,,
Leaves removed as showing incipient rotting ...	2,096	,,
	6,232	,,

Of these, as already remarked, all except the first lot would be saleable.

At the end of all the operations we have, in percentages,

Unbleached leaves remaining	12·3
Bleached leaves	52·0
Partially or wholly rotten leaves	35·7

The temperature records in the above *bhati* are shown in the table opposite :—

In connection with these temperature records, it may be interesting to give figures indicating the rates of bleaching and of becoming rotten in the upper layer of leaves, and in the remainder of the basket.

March 15th, 1912.

	Upper layer.	Remainder of *bhati*.
Bleached leaves	2·9 per cent.	2·4 per cent.
Leaves not yet bleached	85·3 per cent.	81·9 per cent.
Leaves more or less rotten	11·8 per cent.	15·7 per cent.

March 29th, 1912.

	Upper layer.	Remainder of *bhati*.
Bleached leaves	54·2 per cent.	60·4 per cent.
Leaves not yet bleached	29·2 per cent.	21·8 per cent.
Leaves more or less rotten	16·6 per cent.	17·8 per cent.

These would seem to indicate that the higher temperature in the lower layers at the commencement of the process leads to an increase in the number of rotten leaves, but not to an increase in the amount of bleaching. At the latter part of the

process, when there was no difference of temperature, the bleaching went on a little more rapidly in the lower layers.

The progress of the bleaching process was followed at every stage by determination of the amount of the constituents which seemed likely to be important as indicated in Part II of the present paper. The methods there indicated were adopted in the estimation.

(1) *Sugars.*—The changes which occurred during the process are indicated in the following table :—

Date, 1911.	Character of sample.	Reducing sugars.	Non-reducing sugars.	Total sugars.
		Per cent.	Per cent.	Per cent.
November 1st ...	Fresh leaves	0·43	1·30	1·73
November 10th	(*a*) Unbleached	0·43	0·70	1·13
	(*b*) Partially bleached ...	0·49	0·51	1·01
	(*c*) Bleached	0·83	0·50	1·32
November 16th	(*a*) Unbleached*	0·50	0·71	1·21
	(*b*) Bleached	0·83	0·41	1·24
November 21st	(*a*) Unbleached*	0·64	0·46	1·10
	(*b*) Bleached	0·82	0·33	1·15
November 30th	(*a*) Unbleached*	0·76	0·37	1·13
	(*b*) Bleached	0·83	0·29	1·12

* In this case all leaves not bleached enough for removal, and fit for further treatment have been classed as unbleached leaves.

These results seem very definite. There is a rapid loss of total sugars in the early part of the bleaching process. Thereafter the amount falls only very gradually. The character of the reducing sugars in the bleached leaves is wonderfully constant. Thus we have :—

Leaves.	Reducing sugars.	Non-reducing sugars.	Total sugars.
	Per cent.	Per cent.	Per cent.
After ten days bleaching	0·82	0·50	1·32
After sixteen days bleaching	0·83	0·41	1·24
After twenty-one days bleaching	0·82	0·33	1·15
After thirty days bleaching	0·83	0·29	1·12

At all stages the reducing sugar seems to have reached a constant amount in the bleached leaves, the non-reducing sugar

being the constituent which gradually falls. At every stage, too, the leaves which have not bleached do not contain as much reducing sugar as, and do contain more non-reducing sugar than, the fully bleached leaves. The following figures from the leaves which did not bleach compare well with those last given :—

LEAVES.	Reducing sugars.	Non-reducing sugars.	Total sugars.
	Per cent.	Per cent.	Per cent.
After ten days bleaching	0·43	0·70	1·13
After sixteen days bleaching	0·50	0·71	1·21
After twenty one days bleaching .. .	0·64	0·46	1·10
After thirty days bleaching	0·76	0·37	1·13

At the end of the process it will be seen, however, that the character of the sugars in the leaves which refuse to bleach is gradually approaching that in the bleached leaves. It would appear, therefore, that with regard to the sugars an identical or similar reaction is taking place to that which has taken place in the bleached leaves,—but it goes on much more slowly.

(2) *Starch.*—The changes in the amount of starch are as interesting as those which take place in the sugars. The following table gives the actual figures obtained : —

Date, 1911.	Character of sample.	Starch. Per cent.
November 1st	Fresh leaves	3·10
November 10th	(a) Unbleached	3·07
	(b) Partially bleached	2·90
	(c) Bleached	2·89
November 16th	(a) Unbleached*	2·46
	(b) Bleached	1·92
November 21st	(a) Unbleached*	2·68
	(b) Bleached	1·90
November 30th	(a) Unbleached*	1·52
	(b) Bleached	1·44

* In this case all leaves not bleached enough for removal, and fit for further treatment, have been classed as unbleached leaves.

The amount of starch gradually diminishes in all the leaves, whether they are bleaching or no. The loss of starch, however,

goes on much faster in the leaves which bleach than in those which refuse to do so, at any rate until the last stages of the process. At the second and third turning of the leaves a constant position of the starch seems almost to have been reached,—but this is shown not to be really the end of the process for a very considerable further reduction takes place after the twenty-first day.

Taking the figures for the sugars and the starch together we may say that in the *bhati* we are discussing

(1) The reducing sugars rose to a constant amount in the bleached leaves.

(2) The non-reducing sugars suffered a constant decrease during bleaching.

(3) The starch suffered a constant decrease during bleaching.

(4) These changes invariably took place faster in the leaves which bleached easily than in those which would not do so.

Though the experimental *bhati* we have quoted and for which we have given the results is the most complete we have made, these same points with regard to the sugars and starch seem to be indicated in other cases in which we have carried out the process. The following are the figures obtained for a *bhati* worked from September 1st to 9th, 1911. In this case the leaves were *narati*, but were considered fit for bleaching. The leaves had been plucked several days before the *bhati* was set. This, however, is considered no disadvantage. The figures were as follows :—

Date, 1911.	Character of sample.	Reducing sugars.	Non-reducing sugars.	Total sugars.	Starch.
		Per cent.	Per cent.	Per cent.	Per cent.
September 1st	Fresh leaves	0·39	0·55	0·94	2·01
September 9th	(*a*) Unbleached	0·40	0·51	0·91	1·96
	(*b*) Bleached	0·28	0·25	0·53	1·64
September 14th	(*a*) Unbleached	0·32	0·37	0·69	1·70
	(*b*) Partially bleached	0·34	0·27	0·61	1·73
	(*c*) Bleached	0·40	0·30	0·71	1·51
September 19th	(*a*) Unbleached	0·36	0·45	0·81	1·16
	(*b*) Bleached	0·39	0·38	0·77	1·01

Here, though the condition of the leaf at the beginning with regard to the content of sugars and starch precluded apparently the striking results obtained with regard to the reducing sugars in the former case, yet in nearly all other particulars the results agree with the conclusions above given. There is the reduction in the amount of starch, the reduction in the amount of non reducing sugars, taking place more rapidly, as a rule, in the bleached than in the unbleached leaves, and the fact that the reducing sugars do not decrease,* although they do not increase as in the *bhati* previously reported.

The results of a third *bhati* may also be reported, taken at an even more favourable season than the last two, and with *junawan* leaves, considered specially suitable for bleaching. The *bhati* was set on June 13th, and lasted till June 27th, and so far as sugars and starch were concerned, gave the following results :—

Date.	Kind of Leaves.	Reducing sugars.	Non reducing sugars.	Total sugars.	Starch.
		Per cent.	Per cent.	Per cent.	Per cent.
June 13th ...	Fresh leaves	0·53	0·97	1·50	1·78
June 16th ..	(*a*) Unbleached ...	0·74	0·62	1·36	1·80
	(*b*) Showing signs of bleaching	0·74	0·82	1·56	1·70
June 19th ...	(*a*) Unbleached .	0·56	0·97	1·53	1·34
	(*b*) Bleached	0·62	0·42	1·04	1·76
June 23rd	(*a*) Unbleached and partially bleached only ...	0·88	0·43	1·31	0·91
	(*b*) Bleached	0·96	0·40	1·36	0·92
June 27th ...	(*a*) Unbleached and partly bleached only ..	0·75	0·35	1·10	0·86
	(*b*) Bleached	0·95	0·29	1·24	0·73

Again the results are, on the whole, similar to what we have seen in the previous cases.

(3) *Tannin.* -We may now turn to a consideration of what happens to the tannin during the process of bleaching. The method of estimation is, no doubt, an imperfect one, but it represents, at any rate, the changes taking place in a particular class of substances, if not in any one chemical individual.

* Omitting the analysis of the bleached leaf on September 9th which seems peculiar, and which we cannot account for.

(a) *Bhati set on November 1st*, 1911.

Date.	Kind of Leaves.	Tannin.
		Per cent.
November 1st ...	Fresh leaves	2·05
November 10th ...	(*a*) Unbleached	2·90
	(*b*) Partially bleached	2·00
	(*c*) Bleached	1·63
November 16th ...	(*a*) Unbleached	1·84
	(*b*) Bleached	1·87
November 21st ...	(*a*) Unbleached	2·10
	(*b*) Bleached	1·63
November 30th ...	(*a*) Unbleached	1·62
	(*b*) Bleached	1·89

(b) *Bhati set on June 13th.*—These leaves were in excellent condition for bleaching.

Date.	Kind of Leaves.	Tannin.
		Per cent.
June 13th	Fresh leaves	1·84
June 16th	(*a*) Unbleached	1·79
	(*b*) Partially bleached	1·70
June 19th	(*a*) Unbleached	1·84
	(*b*) Bleached	1·92
June 23rd ...	(*a*) Partially bleached	1·79
	(*b*) Bleached	2·07
June 27th ...	(*a*) Partially bleached	1·80
	(*b*) Bleached	2·03

(c) *Bhati set on September 1st.*—These leaves were of *navati* type, but were considered good enough for bleaching.

Date.	Kind of Leaves.	Tannin.
		Per cent.
September 1st	Fresh leaves	1·01
September 9th	(*a*) Unbleached	1·05
	(*b*) Bleached	1·32
September 14th ..	(*a*) Unbleached	1·03
	(*b*) Partially bleached	1·18
	(*c*) Bleached	1·36
September 19th ...	(*a*) Unbleached	1·10
	(*b*) Bleached	1·23

(d) *Bhati set on November 13th*, with *narati* leaves usually considered as unfit for bleaching. They bleached very badly.

Date.	Kind of Leaves.	Tannin.
		Per cent.
November 13th ..	Fresh *narati* leaves	3·26
November 16th	No change in colour	2·03
November 19th ...	Leaves slightly changing in colour	2·05
November 23rd ..	Leaves slightly changing in colour	2·32
November 27th ..	Leaves bleached	2·38

These results, taken as they are from leaves bleaching in various times of the year, and under very varying conditions do not seem to indicate any very large change in the percentage of tannin in the process. In fact the actual figures would seem to indicate no relationship between the bleaching and the percentage of tannin whatever. Certainly the extra value of the bleached leaves does not depend on any increase of astringency due to increase in the amount of tannin.

Judged from a wider standpoint, these figures do not indicate any tendency of the tannin to disappear by any process of auto-digestion in these leaves, separated as they are from their plant, and yet still living, nor on the other hand do they indicate that the tannin is a waste product which they produce,—or else one might expect under these conditions that the tannin would markedly increase.

4. *Ether Extract.*
5. *Essential Oil.*

The figures which we can present with regard to the ether extract and the essential oil date from more recent *bhatis* than those which have furnished the results for starch, sugar and tannin. The actual data here given are obtained from the process set on March 9th, 1912, with *junawan* leaves of the best kind, most suitable for bleaching.

Date, 1912.	Kind of Leaves.	Ether Extract. Per cent.	Essential Oil. Per cent.
March 9th ...	Fresh leaves	15·7	1·23
March 13th ...	(a) Unbleached leaves	13·1	1·26
	(b) Partly bleached leaves	12·9	2·23
	(c) Bleached leaves	13·0	4·76
March 21st	(a) Unbleached leaves	13·5	1·41
	(b) Bleached leaves	13·7	5·20
March 24th ...	(a) Unbleached leaves ...	11·3	1·28
	(b) Bleached leaves ...	13·5	4·20

We shall have no more to say with regard to the total ether extract. It evidently indicates nothing which is important from the present point of view. But the figures for the essential oil are very striking indeed. During the bleaching process,—and evidently intimately connected with the bleaching itself, there is a very large increase in the amount of essential oil. In one case it actually becomes four times as great in amount as it was in the original leaf, while in the leaves which refuse to bleach it remains almost constant in amount throughout.

This result is, in accordance, of course with the view that the essential oil is the constituent which gives their main value to betel-vine leaves, for the bleached leaves are usually worth three times at least as much as the fresh leaves.*

Considered as a point in plant physiology, it is difficult to explain, but it might be worth while to draw attention again to the fact that one of us (H. H. Mann) found a considerable increase in the essential oil of the tea leaf during the "withering" or rather 'wilting' process in the manufacture, which has certain analogies with the process of bleaching which we are discussing.

The increase in essential oil during the bleaching of the leaf was so striking that it seemed worth while to see if a microscopical examination of the leaf would indicate in what way the increase in oil occurred. Sections of the fresh and bleached leaf

* *Vide* above for prices in Poona Bazaar.

were, therefore taken,—and the following observations were made.

Fresh Leaves.—In these there were two kinds of oil globules, one type much larger than the other. The larger ones were transparent and seen in all parts of the leaf and were about 0·4 millimetre in diameter. The small ones were semi-transparent, and were seen all over the surface, were quite circular or elliptical, and were surrounded by chlorophyll grains, and were about 0·1 millimetre in diameter.

Bleached Leaves.—In these the small oil globules had become very much more numerous than before, and were clearly seen all over the surface. The larger globules were not affected, and their appearance and number remained very similar to what had been seen in fresh leaves.

6. *Acidity.*—The acidity, determined as previously indicated and expressed as the number of cubic centimetres of one-tenth normal caustic potash solution required to neutralise the acidity in one hundred grammes of leaves, is shown in the various stages of a typical *bhati* in the following table :—

Date, 1911.	Kind of Leaves.	Acidity (as above defined).
November 1st	Fresh leaves	112·8
November 10th	(a) Unbleached	108·0
	(b) Partially bleached	97·0
	(c) Bleached	120·0
November 16th	(a) Unbleached	85·0
	(b) Bleached	150·0
November 21st	(a) Unbleached	93·0
	(b) Bleached	161·0
November 30th	(a) Unbleached	115·0
	(b) Bleached	180·0

These figures are striking. The bleaching is accompanied by a very large increase of acidity, which becomes greater the longer the time the bleaching takes. In the leaves which do not bleach, the fact of keeping leads to little or no increase in acidity.

7. *Diastatic Activity.*—The following figures were obtained from a *bhati* conducted early in 1912 :—

Date.	Kind of Leaves.	Diastatic activity.*
March 9th	Fresh leaves	24·8
March 15th ...	(a) Unbleached	23·4
	(b) Partially bleached	15·5
	(c) Bleached	14·8
March 21st	(a) Unbleached	16·7
	(b) Bleached	11·5
March 24th ...	(a) Unbleached	15·6
	(b) Bleached	12·4

There is evidently a rapid reduction in the diastatic activity of the leaves during keeping under the conditions of the *bhati*, whether bleaching takes place or not. But this reduction is far more rapid, and goes much further when the bleaching is taking place than when this is not the case. This is perhaps what might be expected. The leaf is dying, though in the present case the process is very long,—and it is only natural that a product so characteristic of the living plant, and so intimately connected with the life processes of the leaf should be rapidly reduced during a process like that of bleaching.

8. *Nitrates.*—The determination of nitrates in leaf during the process of bleaching has led to some very curious results, indicating that the process which goes on is by no means always the same. In a *bhati* set in on August 5th, 1912, the following figures were obtained :—

Date.	Kind of Leaves.	Potassium Nitrate.
		Per cent.
August 5th	Fresh leaves	1·07
August 8th ..	Unbleached	1·06
August 12th ..	(a) Unbleached	1·00
	(b) Very slightly changed in colour ...	·99
	(c) Partially bleached	1·00
	(d) Bleached (white)*	·90

* For a definition of what is meant by these figures *vide* supra.

Date.	Kind of Leaves	Potassium Nitrate.
		Per cent.
August 17th ..	(*a*) Unbleached	·74
	(*b*) Very slightly changed in colour ..	·95
	(*c*) Partially bleached	1·05
	(*d*) Bleached (white)*	1·05
August 22nd ..	(*a*) Very slightly changed in colour .	1·07
	(*b*) Partially bleached	1·06
	(*c*) Bleached (white)*	1·17
	(*d*) Bleached (yellow)*	0·04
August 25th	(*a*) Partially bleached	0·98
	(*b*) Bleached (white)*	1·09
	(*c*) Bleached (yellow)*	0·20

* For a definition of what is meant by these figures *vide* supra.

With the exception of one case, of which we will speak directly, the effect of the process we are discussing on the quantity of nitrates in the leaf seems very small indeed. The fresh leaves taken contained slightly more than at almost any subsequent stage of the process. But the difference is small, and one might consider that in a normal bleaching process the nitrates remained unaffected.

In every bleaching process, however, —and more so in the cold weather when bleaching does not take place normally,—a few yellow leaves appear instead of white ones. They are looked on with great disfavour by the *tambolis*, and only command a very poor price in the market compared with those lighter in colour. We hardly suspected, however, how different was the process in the case of these leaves until certain variations in the amount of nitrate in bleached leaves called our attention to it. It was then found, in fact, that while the nearly white, normally bleached leaves contained about the same quantity of nitrates as the original leaves, in the yellow ones the nitrates had practically disappeared. Thus in the above table we have :

		Per cent.	
August 22nd ...	White leaves ...	1·17	KNO_3
	Yellow leaves ...	0·04	KNO_3
August 25th ...	White leaves ...	1·09	KNO_3
	Yellow leaves ...	0·20	KNO_3

These figures led to a closer investigation of the question in four different *bhatis* with results given in the following table.

We have included the examination of some so-called *gajriya* leaves or leaves stated by the *tambolis* as not likely to bleach properly or at all :—

POTASSIUM NITRATE.

	First series.	Second series.	Third series.	Fourth series.
	Per cent.	Per cent.	Per cent.	Per cent.
Fresh leaves (fit for bleaching)	1·05	0·90	1·28	1·86
Fresh *gajriya* leaves (not fit for bleaching) ...	1·17	0·81	0·86	1·67
Bleached leaves, white ...	1·06	0·82	1·32	1·23
Bleached leaves, yellow ...	0·00	0·06	0·10	0·18

These figures confirm, in every particular, the experiment first quoted.

Such are the results obtained by following the process of conversion of green betel-vine leaves into the much more appreciated bleached leaves. In summary we may say that the process is accompanied—

(1) by a very large increase in the amount of essential oil ;
(2) by a very considerable increase in the acidity ;
(3) by a disappearance of a large part of the starch and non-reducing sugars,—a disappearance which, however, is never complete :
(4) usually by an increase in the amount of reducing sugar ;
(5) by no large change in the percentage of tannin ;
(6) by no large change in the amount of nitrates in normally (white) bleached leaves, while the nitrates almost entirely disappear in the leaves which turn yellow during the process ;
(7) by a large decrease in the amount of diastase.

ACTION OF VARIOUS GASES, VAPOURS, ETC., ON THE BLEACHING PROCESS.

At this stage it seemed possible that we might reach a better understanding of the bleaching process, and hence of the betel-vine leaf itself if we attempted to bleach the leaves in

presence of certain gases, or vapours,—or if they would not bleach, by leaving them in contact with such materials. In order to carry this out, a few leaves, usually five, were placed in a dish under a bell jar inside which the air was kept saturated with moisture by standing the bell jar in a dish of water. In the first experiments there was, in spite of all, a great tendency in the leaves to dry up. To avoid this, they were afterwards dipped in water before the experiment was started.

In the first instance, the changes in appearance produced by a number of strong re-agents were noticed for later guidance. The notes made regarding some of these are as follows :—

Air and Water.—No change was apparent either in colour or otherwise to the end of the second day. but on the third the fresh green colour was fading, and giving rise to a faint yellowish appearance. The following day the same change was progressing and bleaching had begun. On the fifth day, the leaves were half bleached to a more yellow tint than is normal, while a day later some of the leaves were more or less bleached, while they had begun to dry at the edge.

Hydrogen Gas (moist).- The leaves did not change in appearance and lustre for the first eight days. On the eighth day the leaves were slightly drying, but the fresh green colour remained. After fourteen days a slight change was seen in the colour. The original fresh colour was disappearing slowly, but beyond this the drying of the edges, etc., was the only noticeable change. A little later the leaves began to rot at the tips without any change in the green colour.

Carbon Dioxide (moist).—On the second day a slight brownish tinge appeared along the border and tip. On the following day the whole of the leaf was bordered by a dark coloured ring, but the general colour of the leaf was unchanged. On the fourth day the dark colour was extending all over the leaf, and slight rotting was noticed at the ends. A day later, the whole leaf had become of a dirty blackish green colour, destroying all lustre. The leaf was distinctly rotting in places.

Oxygen (moist).—The change described as occurring with air took place, but more rapidly with oxygen. On the fifth day the leaves had changed to yellow—the yellow colour being specially prominent at the stalk-end of the leaf. The day after, the leaves were yellow, and had become brittle. The change which had taken place differed in many respects, apparently, from a normal bleaching.

Chlorine Gas (moist).—Only a trace of chlorine was used, but the change was at once apparent. The leaves became reddish brown, all the green colour of the chlorophyll disappeared. They became very thin, changed to a yellow colour, then to brown, and then to white and semi-transparent.

Dipping in Hydrogen Peroxide Solution and then moist air.—Two strengths of solution were used containing respectively three per cent. and one per cent. of Hydrogen Peroxide. With the stronger solution the leaves changed rapidly in colour. On the second day small brown spots appeared everywhere on the surface while the veins had turned black. A day later all the spots had become black. On the fourth day the spots remained black, and the remainder of the leaf had become a faint yellow in colour.

The weaker solution had a very similar effect, but it appeared, of course, more slowly. A few brownish spots here and there were seen on the third day, while on the fourth day the leaves were becoming yellowish in colour. On the fifth day, when the observations terminated, the leaves had become more or less yellow, with a few brown specks, but still retained the lustre of the original leaf.

Ammonia Gas.—A very small quantity of ammonia solution was placed under the bell jar containing the leaves, and the effect noticed. On the second day, a yellowish tinge appeared on the leaves which changed gradually to brown, and on the following day almost the whole surface had become brown in colour. A day later the brown colour had become black, and in just a few places where this colour had not developed, the leaf had turned yellow, but it was in no sense a normal bleaching.

Formic Acid Vapour.—A small quantity of Formic Acid solution was placed under the bell jar.

On the second day big brown and dirty looking patches were seen on the surface of the leaves, while a day later these had extended, and occupied nearly the whole of the surface. On the fourth day, the leaf tips had become black, and the leaves had lost all lustre. The part which had not turned black or brown (a very small amount) was turning to a dirty yellow colour.

Acetic Acid Vapour.—This was used in the same way as Formic Acid vapour.

In this case the action was very rapid. After four hours the leaf had developed brown spots all over, and by the second day these had become brown, changing to black,—while almost all the surface was covered. On the third day, the leaf had lost all lustre and stiffness, looked as if scorched, and was rapidly turning black.

It was at once evident that the effect of some of these reagents was to kill the leaf at once, and the appearances which followed were simply the result of that death of the tissues. Moreover, it is evident that the effect of hydrogen was to prevent bleaching taking place. It appears in every degree probable that reducing agents, or even gases whose presence tends to prevent oxidation, tend to delay or hinder the process.

Further experiments were therefore made with a limited number of reagents as follows :—

(1) Air and water vapour only.

(2) Carbon Dioxide and water vapour.

(3) Oxygen and water vapour.

(4) Trace of Ammonia and water vapour.

(5) Trace of Formic Acid vapour and water vapour.

(6) Leaves dipped in 1 per cent. Hydrogen Peroxide solution and then kept with air and water vapour.

Several experiments were carried out, but the results obtained were so similar that to quote details of one experiment is to quote all. In this one case, the leaves were exposed to these

reagents on 14th June 1912, and the experiment lasted eight days. The daily temperatures at 1 P.M. were as follows:—

June 14th	...	... 29° C.
,, 16th	...	... 30° C.
,, 17th	...	... 30° C.
,, 18th	...	... 28° C.
,, 19th	...	... 29 C.
,, 20th	...	... 27° C.
,, 21st	...	... 27° C.

The appearances were as follows:—

Air and Water Vapour. No change occurred for three days when the green colour of the fresh leaf seemed to be beginning to fade. A day later this was marked, and there was a yellowish tinge all over the leaves which seemed to be proceeding as in an ordinary bleaching operation. On the sixth day this change continued, and the loss of the green colour appeared quite regular, while by the following day some leaves were nearly bleached. A day later rotting had set in, and the operation was closed

Carbon Dioxide and Water Vapour.—After two days little effect was visible except a very slight brownish tinge at the borders of the leaves, which was very marked two days later. At the same time the original green tint had become much darker in the leaves. Shortly afterwards the brownish tinge gradually extended to the remainder of the leaves, and by the seventh day rotting was visible at the ends of the leaf gradually extending to the middle by the eighth day.

Oxygen and Water Vapour.—On the fourth day bleaching became marked, and spread rapidly, commencing at the stalk end. This continued more rapidly than in the leaves exposed to air, and no rotting occurred till the seventh day, when one leaf showed signs of rotting from the stalk end. When the leaves were taken away on the eighth day, all had changed to yellowish white though not completely, but were rather brittle, and in this respect differed from ordinary well-bleached leaves.

Trace of Ammonia and Water Vapour.—After one day the leaf was noticed to be turning black at certain points, while small patches of brownish yellow colour appeared. Two days later, dirty black spots were seen all over. Some leaves had become blackish. The part not spotted or turned blackish seemed to be bleaching normally, and on the sixth day, was changing in colour to yellow. The colour was, however, an objectionable yellow, developing from the stalk end. All lustre was lost. No further change took place except the gradual rotting of the blackened and spotted part.

Trace of Formic Acid Vapour and Water Vapour.—On the second day, a brownish colour began to appear in large and small patches, which were, however, not by any means uniform. This rapidly extended all over the surface of the leaves, which turned a dirty blackish colour, with complete loss of lustre. Rotting rapidly set in, and mould began to grow on the leaves.

Dipping in 1 per cent. Hydrogen Peroxide, and then keeping with Air and Water Vapour.—No change occurred till the fourth day, when very small brown patches were seen on some parts of the leaves, while the original green colour was slowly fading over the remainder. The same condition persisted and progressed. Finally after eight days leaves fairly well bleached were obtained spotted over, in many parts, however, with black spots. The resulting leaves were very brittle.

Inasmuch as the increase in the essential oil seems to be the most important chemical change taking place during a normal bleaching, determinations were made of this constituent under the various treatments in special lots set on for this purpose. The results are shown in the following table :—

ESSENTIAL OIL IN DRY LEAF.

	Moist Air.	Carbon Dioxide.	Oxygen.	Trace of Ammonia.	Trace of Formic Acid.	Dipped in Hydrogen Peroxide.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
After 24 hours	1·5	1·0	1·3	0·3	...	...
After 4 days	2·7	2·1	3·9	0·7	2·8	2·7
After 5 days	3·1		3·4	...	...	..
After 6 days	2·8	...	...	..	...	.

These figures show a gradual increase in the essential oil in moist air. It never reaches the proportion produced under the conditions of an ordinary *bhati*, but is in the same direction. With oxygen there is the same increase in the essential oil, which indeed reaches higher proportions than with air. Before the operations were stopped, however, the essential oil seemed to be again decreasing in amount.

With Carbon Dioxide, the increase in essential oil seems to be very much less.

The presence of a trace of Ammonia leads to the almost complete destruction of the essential oil. A trace of Formic Acid, on the other hand, does not seem to affect this, and the amount produced after four days is similar to that produced under the ordinary conditions with air.

Dipping in dilute Hydrogen Peroxide does not seem to have affected the development of essential oil.

As a whole, as a result of these experiments, it is evident that the process which takes place during bleaching is one of oxidation. Anything which prevents oxidation, prevents bleaching and prevents the development of essential oil. Moreover slight acidity is a necessary condition: the slightest trace of alkalinity (as with Ammonia Vapour) leads to the almost complete destruction of the essential oil and of the leaf.

Such are the results which we have obtained so far. As regards the commercial bleaching of the betel-vine we have shown how it is carried out, the conditions under which it is most successful, and in some measure the chemical changes by which it is accompanied. It remains to clear up more completely the nature of these changes, to examine more closely the manner in which the essential oil varies during the process, and to ascertain whether it is a change in kind as well as in quantity, and to investigate more closely the differences between leaves bleaching in different ways. Finally it is necessary to make further experiments to see whether the process can be expedited in any way

without loss in quantity in the final product, and so whether the present cumbrous and wasteful process cannot be modified so as to make it quicker, cleaner, and more satisfactory, leading to less loss of leaf through ordinary rotting and decay. We are actively continuing the work in these directions.

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THEIR COMPOSITION AND RELATIONSHIP TO THE CROP

BY

W. H. HARRISON, M.Sc.
Government Agricultural Chemist, Madras

AND

P. A. SUBRAMANIA AIYER, B.A.
Assistant to the Govt. Agri. Chemist

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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INTRODUCTORY.

IRRIGATED paddy or rice in South India is generally grown under swamp conditions throughout the growing season and in a puddled soil, *i.e.*, ploughed or levelled in water, but no general system of cultivation holds good, nor can it be said that what is found to be successful in one place will answer in another. On the South Malabar Coast, it is the general practice to plough the lands in the dry season with excellent results, but this same custom introduced into other districts has led to failure. Paddies which flourish in one delta or district often do not do so well when transferred to another place where the conditions are apparently of a similar character. Green-manuring is found to answer perfectly well in one area, but when tried in another area the crop fails. In one district the water may be run on to fields and the latter puddled and manured weeks before the crop is planted, but in other districts, the custom is to put in the green-manure just before the time of transplanting. These and the many other mutually opposed facts which can be quoted, make it essential that the conditions governing the growth of paddy should be closely studied in order to obtain,

if possible, some common basis capable of explaining them before material improvement can be made in paddy cultivation.

On considering the problem in all its general aspects, it was felt that a study of the soil gases formed the most promising field of enquiry, and the results obtained, as well as some from closely connected investigations, are detailed in the following pages.

Before proceeding to a consideration of the investigation, a brief description of the cultural conditions of Swamp Paddy Soils in South India will make clear the peculiar conditions under which the crop is grown and also clearly demark the scope of the enquiry and the application of the results.

In general, these soils are allowed to lie in an uncultivated condition during the hot season, during which period they dry to a considerable extent and, owing to their very heavy character, shrink considerably and wide cracks are formed reaching down to a depth of from two to three feet. This deep cracking of the soil leads to complete aeration, and no doubt nitrification proceeds apace at this time. On the South Malabar Coast, however, the land is systematically worked over during the dry season. As soon as water is available seed-beds are formed where the paddy germinates and grows until the time of transplanting arrives. Some time before transplanting water is admitted to the fields, which are then thoroughly ploughed and puddled, and the heavy crop of weeds formed on the dry soil is worked in. In addition, wherever available, large quantities of green-leaf manure are thoroughly incorporated with the soil by the trampling of cattle or coolies.

The amount of green-manure used varies with its availability and cost, but often the cultivators will scour the dry land for miles around to obtain it, and the use of as much as 4,000—5,000 lbs. per acre is quite common. In the deltas green-leaf manure is very scarce, and its use is not so common, but even there the seed-beds are heavily manured. In the Kistna Delta it is a common practice to sow sunn-hemp (*Crotalaria juncea*) just before harvesting the paddy and the resultant crop is used as fodder, but the straw and roots are ploughed into the soil.

After puddling and manuring the surplus water is allowed to drain off and the seedlings are transplanted. After transplanting, wherever the conditions permit, water is not allowed to stand in the fields until the seedlings are established, but care is taken to keep the moisture conditions such that no cracking or shrinking of the soil takes place. When the seedlings are established water is admitted in quantity and the whole of the fields are kept under water throughout the rest of the growing season, but, if possible, the land is drained just before harvest to permit of the drying off of the crop.

The main features, then, of paddy cultivation in South India are: (1) the maintenance of swamp conditions by the use of large quantities of water and by puddling the soil and so decreasing the natural drainage; (2) the use of large quantities of green-manures. It is obvious that under these circumstances the soil conditions must be quite dissimilar to those obtaining in dry soils and that the course of the decomposition of the manure and the nutrition of the plant must also be very different.

PART I.

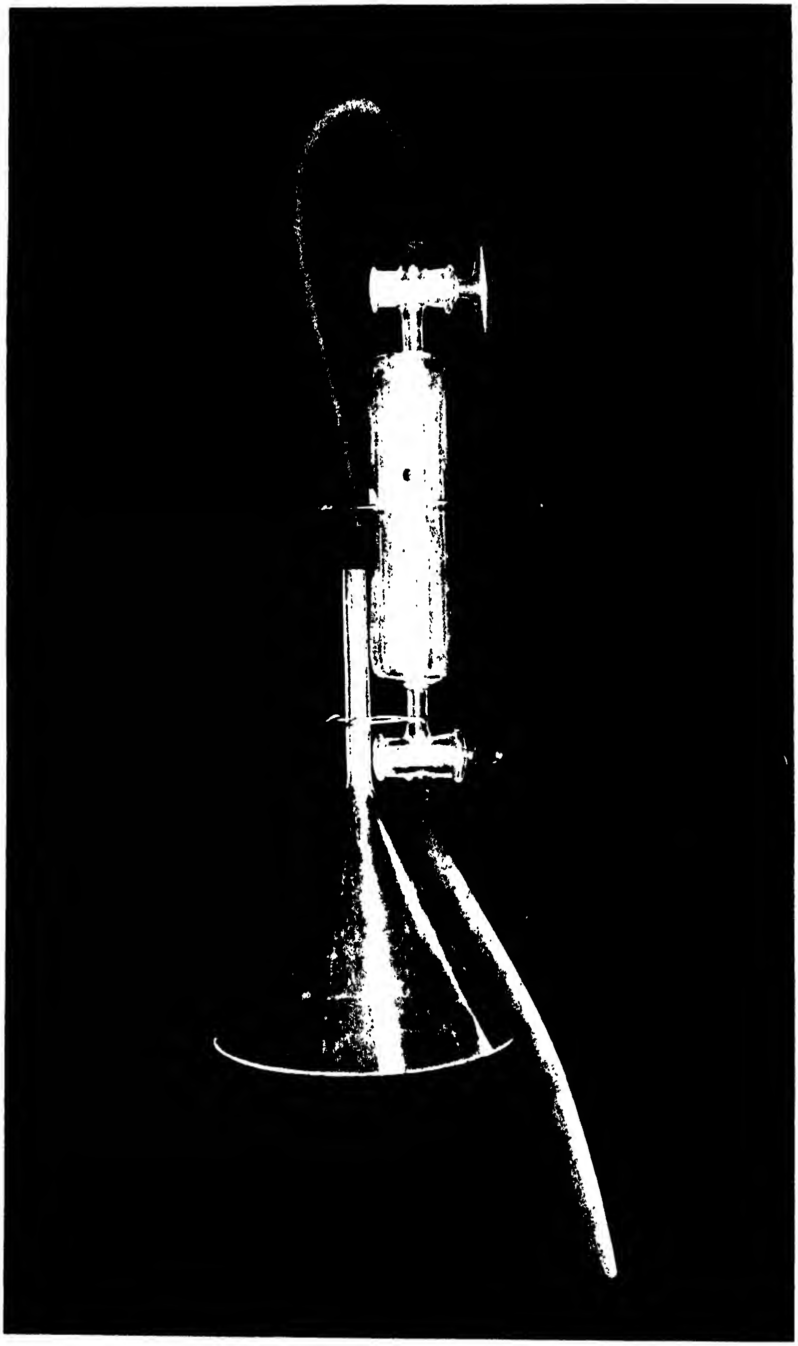
THE GASES OF THE SOIL, THEIR COMPOSITION AND RELATIONSHIP TO THE GROWTH OF THE CROP.

The variations in the composition of the Soil gases.

ON forcing a stick into the soil of paddy fields or on disturbing it in any other manner, bubbles of gas are given off which are easily collected and which on analyses are invariably found to consist mainly of Methane and Nitrogen. The proportion these gases bear to one another varies greatly, the Methane from about 15 to 75 per cent. of the total and the Nitrogen from about 10 to 95 per cent. In addition, Carbon-dioxide is generally present together with small amounts of Oxygen and Hydrogen. Other gases were tested for at intervals, but only those mentioned above have been detected. The amount of Carbon-dioxide present is, on the average, about 5 per cent., but this value may fall as low as 1 per cent. and rise as high as 20 per cent. The amount of Oxygen is usually only a trace, but values as high as 5 per cent. have occasionally been met with. Hydrogen is generally absent but as much as 10 per cent. has been recorded in uncropped plots.

Early in the course of the investigation, it was noticed that in cropped fields the proportion of Methane was generally low, whereas, in uncropped fields this gas greatly predominated and, consequently, the variations in the composition of the gas were particularly studied. To this end, a particular field was chosen and the gases were collected and analysed at intervals from the time of puddling in the green-manure to the time when the land was drained for ripening.

Several different methods of collecting the gas were tried, but the one found to answer best was to walk slowly across a field



Apparatus used for the collection of the Gases of Swamp Paddy Soils.

holding the apparatus figured in Plate I so that the funnel was always under the water. This apparatus consists merely of a large gas tube with a glass stop-cock at either end. The upper one is connected by means of a rubber tube to the collecting funnel, and to the lower one a piece of rubber tube is attached so as to permit of the water in the apparatus discharging below the surface of the water in the field. The whole is filled with water and that portion of the escaping gas collected by the funnel is conveyed to the gas tube, where it is easily isolated. The gases were collected by walking slowly across a field and holding the apparatus over the places of disturbance. This method of collection had the advantages, (1) that an average sample of the whole field was easily made and, (2) an approximate measure of the relative amounts of gas in the soil of different fields was obtained. The gas collected was conveyed to the laboratory and analysed at once. Several types of gas-analysis apparatus were used, but the one found most suitable was a modified form of Adeney's apparatus.

For the estimation of the Methane and Hydrogen, the method of exploding with Oxygen was mainly relied upon but the results were often checked by the method of combustion in a capillary platinum tube, especially when the proportion of Methane was low.

The results obtained during the year 1909 are tabulated below :—

TABLE I.

Showing the composition of the gases from a cropped and manured field during the year 1909.

Date.	% CH_4	% N	% CO_2	% O	% H
August 2nd, 1909	73·8	10·9	14·6	·7	*Nil.*
" 9th "	54·2	36·1	9·7	*Nil.*	..
" 16th "	67·4	21·4	11·2	Trace.	"
" 24th "	73·4	16·2	10·4	"	"
September 1st "	71·2	24·1	4·5	·2	"
" 18th "	64·3	26·5	9·0	·2	..
October 5th "	21·0	72·9	5·6	·5	..
" 26th "	21·4	67·7	10·7	·2	"
November 17th "	23·9	68·8	4·5	2·8	"

In this year, green-manure to the extent of 4,000 lbs. to the acre was ploughed in on July 27th, but the transplanting did not take place until September 7th, and during the whole of this period the percentage of Nitrogen remained low and that of Methane high. Some four weeks after transplanting, a decided change in the composition of the gas took place, and the Nitrogen, instead of being low as formerly, now predominated and continued so as long as it was possible to obtain samples of gas.

So far as it could be determined, the volume of gas in the soil was greater during the latter period, and it therefore appeared as if the presence of a crop brought about a loss of the Nitrogen of the soil and manure and also prevented the formation of Methane. Another important feature was that the soil conditions are anærobic so long as water is over the surface. The fact that the presence or absence of a crop appeared to determine the composition of the soil gases was surprising, and consequently the experiment was repeated in 1910 on a different field with a different type of paddy, and the result was strictly parallel to the former experiment.

TABLE II.

Showing the composition of the Soil gases in a cropped and manured field during 1910.

Date.	% CH_4	% N	% CO_2.	% O	% H
August 6th, 1910	66·2	11·0	20·9	1·9	*Nil.*
,, 12th ,, ...	71·3	12·2	16·5	Trace.	,,
,, 19th ,, ...	56·3	37·1	6·6	,,	,,
,, 26th ,, ...	63·1	32·0	4·4	·5	,,
September 2nd ,, ...	68·5	21·8	9·7	Trace.	,,
,, 9th ,, ...	58·1	36·8	5·1	,,	,,
,, 19th	57·4	35·9	6·7	,,	,,
October 1st ,, ...	33·4	62·8	3·1	·7	,,
,, 6th ,, ...	18·5	78·1	3·2	·2	,,
,, 14th ,, ...	24·3	70·3	5·0	·4	,,
,, 21st ,, ...	17·2	76·9	5·6	·3	,,
November 5th ,, ...	21·0	71·2	5·6	Trace.	2·2
,, 11th ,, ...	18·4	75·0	5·1	*Nil.*	1·5
December 3rd ,, ...	31·9	65·5	2·6	,,	*Nil.*
,, 10th ,, ...	34·0	60·3	3·9	Trace.	1·8
,, 17th ,, ...	36·3	60·3	3·4	*Nil.*	*Nil.*
,, 24th ,, ...	38·6	59·4	2·0	Trace.	,,

CHART NO. 1.

DIAGRAM SHOWING THE VARIATIONS IN THE PERCENTAGE OF NITROGEN IN PADDY-SOIL GASES.

% NITROGEN IN 1909 ————

" " 1910 - - - - - -

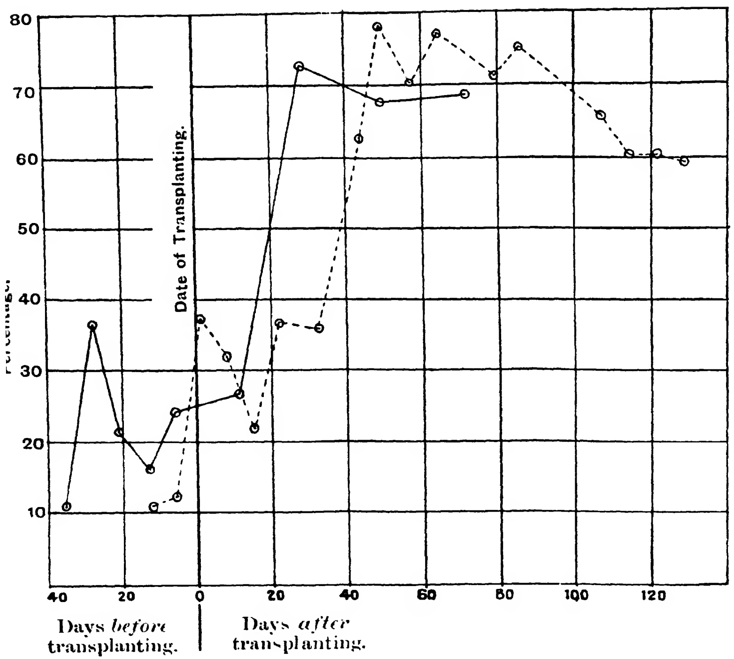


CHART NO. 2.

DIAGRAM SHOWING THE VARIATIONS IN THE PERCENTAGE OF METHANE IN PADDY-SOIL GASES.

% METHANE IN 1909 ————

" " 1910 - - - - - -

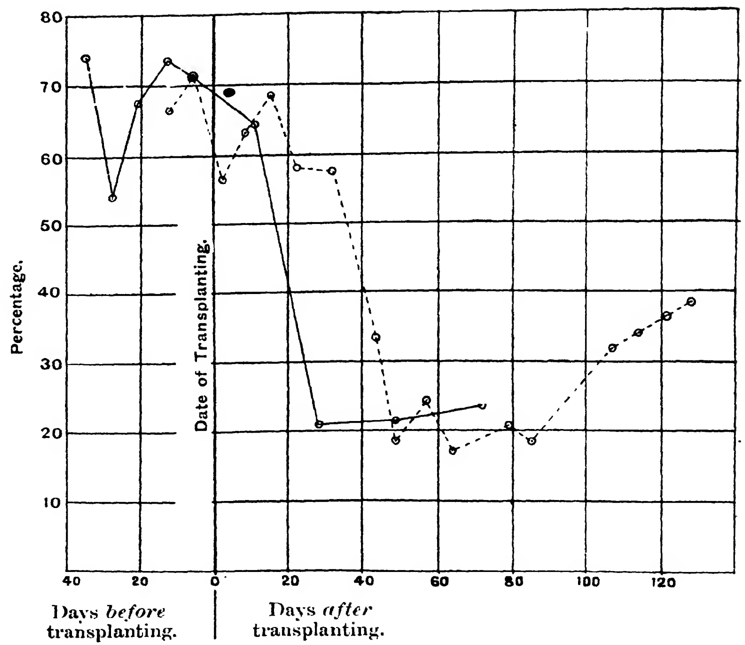


CHART NO. 3.

DIAGRAM SHOWING THE VARIATIONS IN THE PERCENTAGE OF NITROGEN IN THE GASES OF CROPPED AND UNCROPPED PADDY SOILS.

% NITROGEN IN GAS FROM CROPPED SOIL - - - - - - - -
" " " " UNCROPPED SOIL ————

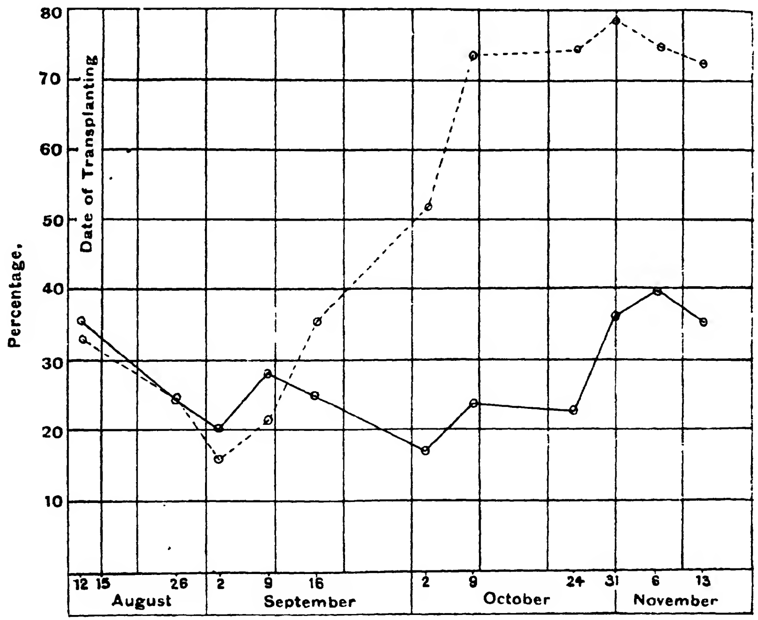
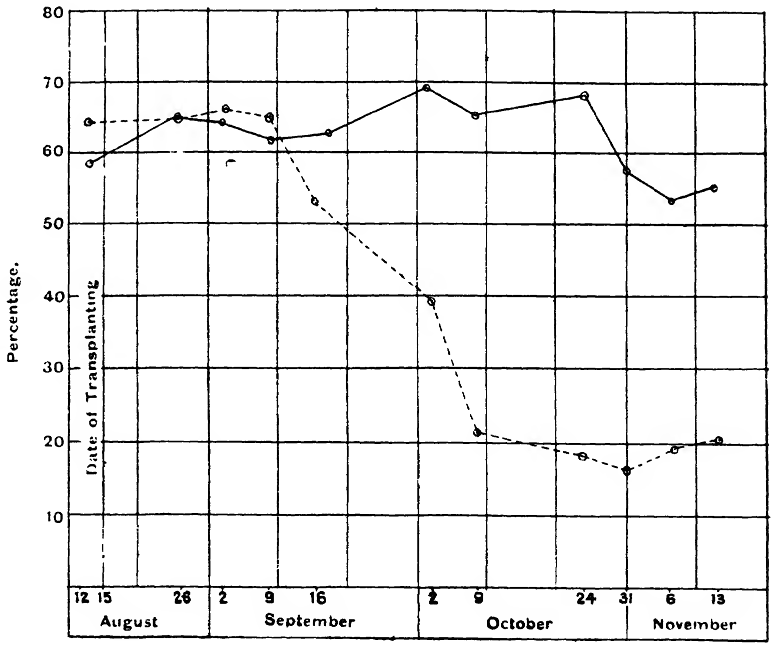


CHART NO. 4.

DIAGRAM SHOWING THE VARIATIONS IN THE PERCENTAGE OF METHANE IN THE GASES FROM CROPPED AND UNCROPPED FIELDS.

% METHANE IN GAS FROM CROPPED FIELD - - - - - - - -
" " " UNCROPPED FIELD ————



This field was manured and puddled on August 3rd, and transplanting took place on August 18th. Here, again, the Methane predominates until the latter part of September, about 5 weeks after transplanting, but from then onwards the Nitrogen predominates.

The values for the percentages of Nitrogen and Methane obtained in these two experiments are plotted out in Charts Nos. 1 and 2, the dates in both cases being referred to the date of transplanting so that the curves are comparable. These curves show clearly the change in the composition of the gas about thirty days after the date of transplanting, but in order to make this point absolutely certain, the following experiment was carried out in 1911.

A small field was taken which had been under paddy cultivation for many years, and which in its known history had received no manure. Such a field has a very uniform texture and composition and is very well suited to experimental work on paddy. The field was divided into four plots by means of small earthen banks (bunds) and two of these plots were manured with green-manure to the extent of 8,000 lbs. per acre. The other two received no manure. Of the manured plots, one was cropped and one left uncropped and the gases from each were collected and compared. In the same way one of the unmanured plots was cropped and the other left uncropped. The gases were collected from all the plots on the same days and the results clearly show the influence of the crop on their composition. The manured plots will be considered first.

TABLE III.

Showing composition of gases from the uncropped manured plot.

Date.			% CH_4.	% N	% CO_2.	% O	% H
August 12th, 1911	..	..	58·6	35·6	1·7	2·2	1·9
,, 26th ,,	..	..	65·0	24·2	2·1	*Nil.*	8·7
September 2nd ,,	..	..	64·4	20·1	3·0	1·0	11·5
,, 9th ,,	..	..	62·2	28·1	2·4	*Nil.*	7·3
,, 16th ,,	..	..	62·7	24·9	2·8	1·1	8·5
October 2nd ,,	..	..	69·4	17·0	4·0	·8	8·8
,, 9th ,,	..	..	65·0	23·8	3·1	·8	7·3
,, 24th ,,	..	..	68·6	22·6	3·7	*Nil.*	5·1
,, 31st ,,	..	..	57·3	35·9	2·6	,,	4·2
November 6th ,,	..	..	53·4	39·9	1·8	,,	4·9
,, 13th ,,	..	..	55·4	35·3	1·6	·3	7·4

TABLE IV.

Showing the composition of gases from cropped and manured plot.

Date.			% CH_4	% N	% CO_2	% O	% H
August	12th, 1911	.. ..	64·4	33·0	1·4	1·2	*Nil.*
„	26th	.. .. ..	64·8	24·5	2·5	·8	7·4
September	2nd	.. .. ..	66·1	15·8	4·9	1·9	11·3
„	9th	.. .. ..	64·5	21·4	4·1	*Nil.*	10·0
„	16th	.. .. ..	52·1	35·5	3·3	1·2	7·9
October	2nd	.. .. ..	39·7	51·6	6·6	·8	1·3
„	9th	.. .. ..	21·0	73·7	4·5	·8	*Nil.*
„	24th	.. .. ..	18·2	74·7	5·7	*Nil.*	1·7
„	31st	.. .. ..	16·6	78·8	4·4	·2	*Nil.*
November	6th	.. .. ..	19·5	75·2	4·9	·4	„
„	13th	.. .. ..	20·4	72·8	4·9	·3	1·6

In these experiments, green-manure to the extent of 8,000 lbs. per acre was puddled in on July 27th, and the fields were again puddled on July 31st and water let in. They were allowed to remain in this condition until August 15th, when the paddy was transplanted. Other than the presence or absence of a crop the two plots were identical in every way and had similar treatment.

A comparison of the results shown in Tables III and IV brings out very clearly the effect of the crop on the composition of the gases, but this is made more apparent in the diagrams on Charts Nos 3 and 4 where the percentages of Nitrogen and Methane in the gases are plotted in the form of curves. Throughout the whole of the period the percentage of Methane in the gas from the *uncropped* plot was always high and the Nitrogen correspondingly low, whereas in the gas from the *cropped* plot the usual change in composition took place about thirty days after the time of transplanting.

The proportion of Methane falls and that of Nitrogen rises until within six weeks from transplanting their former proportions have been entirely reversed. Another point demanding attention is the behaviour of the crop towards the Hydrogen content of the gases. From the uncropped plot throughout the whole period, and also from the cropped plot up to the time of the change in composition taking place, the gases contained comparatively large proportions of Hydrogen; whereas, after the crop has become fully established

and in strong growth, practically no Hydrogen is present. Thus, besides affecting the relative proportion of Nitrogen and Methane, the crop practically determines the presence or absence of Hydrogen in the soil gases.

The corresponding results for the unmanured plots are given in the following tables :—

Table V.

Showing the composition of the gas derived from the uncropped and unmanured plots.

Date.			% CH_4	% N	% CO_2	% O	% H
August	12th, 1911	.. ..	48·4	42·1	1·6	1·6	6·3
,,	26th ,,	.. ..	31·5	61·4	1·4	5·7	*Nil.*
September	2nd ,,	.. ..	57·2	39·9	2·9	*Nil.*	,,
,,	9th ,,	.. ..	52·1	43·0	3·9	·7	,,
,,	16th ,,	.. ..	34·5	62·7	2·1	·7	,,
October	2nd ,,	.. ..	33·7	60·9	2·4	3·0	,,
,,	9th ,,	.. ..	27·3	62·1	5·1	3·4	2·1
,,	24th ,,	.. ..	38·5	56·1	2·7	*Nil.*	2·7
,,	31st ,,	.. ..	26·4	66·4	2·6	·3	4·3
November	6th ,,	.. ..	34·4	60·6	2·3	·3	2·4
,,	13th ,,	.. ..	32·5	59·2	3·6	*Nil.*	4·7

Table VI.

Showing the composition of the gas derived from the cropped and unmanured plot.

Date.			% CH_4	% N	% CO_2	% O	% H
August	12th, 1911	.. ..	38·7	58·2	1·3	1·2	·6
,,	26th ,,	.. ..		Practically no gas.			
September	2nd ..	.. ..	*Nil.*	96·8	3·2	*Nil.*	*Nil.*
,,	9th ,,	.. ..	53·8	43·1	2·3	,,	·8
,,	16th ..	.. ..	51·6	41·9	2·0	1·4	3·1
October	2nd ..	.. ..	28·3	68·3	3·2	·2	*Nil*
,,	9th ..	.. ..	27·2	67·6	3·7	·6	·9
,,	24th ..	.. ..	12·2	81·5	5·9	·4	*Nil.*
,,	31st ,,	.. ..	17·2	77·5	4·6	·7	..
November	6th ,,	.. ..	20·7	73·2	4·5	*Nil.*	1·6
,,	13th ..	.. ..	19·2	77·5	3·1	·2	*Nil.*

In the case of the unmanured plots, it is at once evident that the changes in the composition of the gases are not so marked as in the case of the manured plots, and neither can so much reliance

be placed on the accuracy of the data obtained in the early stage of the experiment, for, the gas production was exceedingly small and samples sufficient for analysis could only be obtained with great difficulty. Further, in many of the earlier samples the gas obtained was obviously present in isolated pockets in the soil, and they could not be looked upon as forming a representative average of the gas present in the plots. Later, as more and more gas accumulated in the soil, representative samples could be obtained and the results in consequence were more reliable. Notwithstanding this, the curves given in Charts Nos. 5 and 6 show that once the crop was thoroughly established small differences in the composition of the gases, analogous to those of manured soils, were present. Thus, in the gas from the uncropped plot, Hydrogen is present in appreciable quantity, but it is practically absent from the gases from the cropped plot. Again after September 16th, the proportion of Methane is lower and that of Nitrogen higher in the gas from the cropped plot than from the uncropped plot. Consequently, these results may be taken as confirming in part the results obtained from the previous experiment, especially when it is remembered that in these unmanured plots no fresh organic matter was added to the soil. The only organic matter present was that constituting the humus of the soil and, this being the residue left from the fermentations of previous years, would be only comparatively slowly attacked. The main fact made clear, however, is that the crop mainly affects the composition of the gases produced from the decomposition of the manure and has little effect on the composition of the gases evolved from the soil organic matter.

A consideration of the foregoing results leads to the conclusions (1) that the gaseous products of the decomposition of organic matter in swamp paddy soils consist chiefly of Methane and a smaller proportion of Nitrogen together with some Carbon-dioxide and Hydrogen ; (2) that the introduction of a crop into the soil materially affects the course of the fermentation and results in the production of a gas with a low proportion of Methane, a high one of Nitrogen, and a practically complete inhibition of Hydrogen formation.

CHART NO. 5.

DIAGRAM SHOWING THE VARIATIONS IN THE PERCENTAGE OF NITROGEN IN THE GASES FROM CROPPED AND UNCROPPED UNMANURED PLOTS

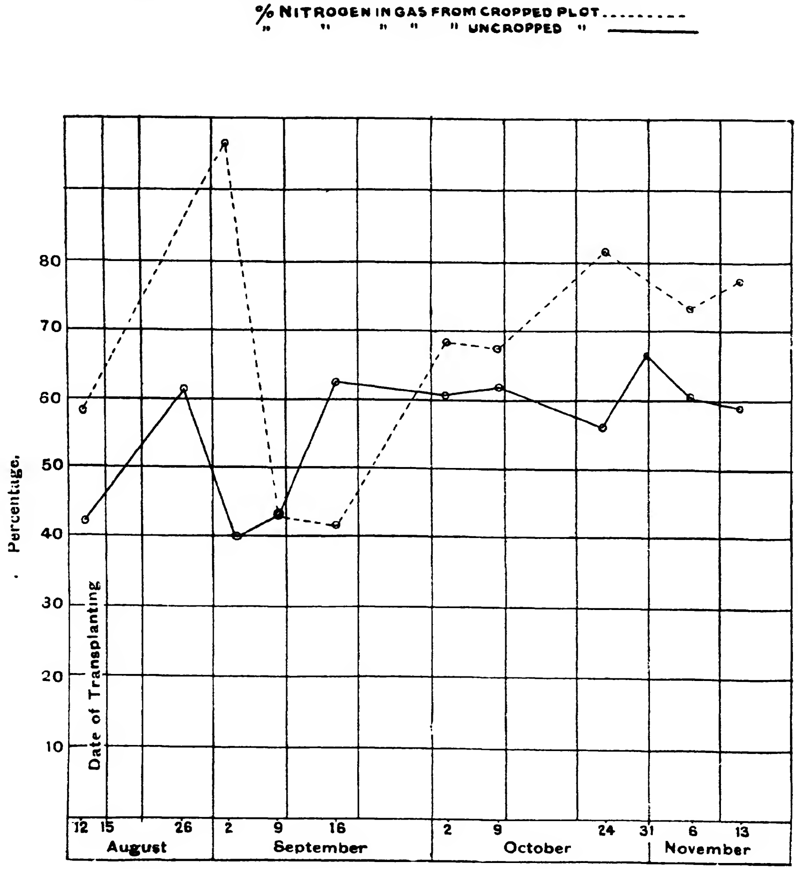
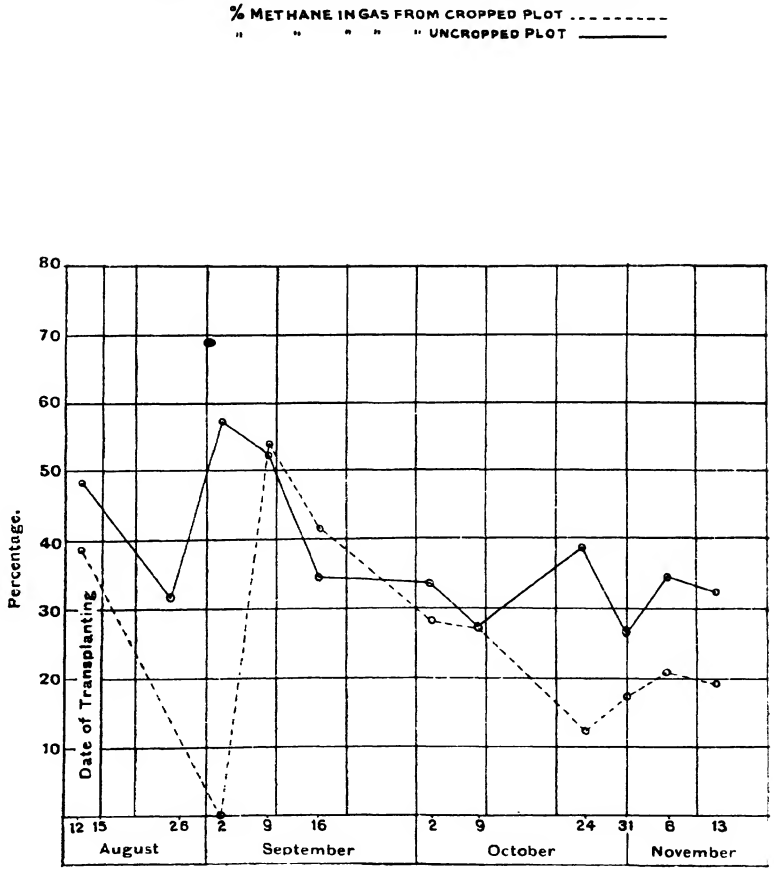


CHART NO. 6.

DIAGRAM SHOWING THE VARIATIONS IN THE PERCENTAGE OF METHANE IN THE GASES FROM CROPPED AND UNCROPPED UNMANURED PLOTS.



The quantity of gas evolved from cropped and uncropped fields.

Before it is possible to determine the true meaning of the change in composition, it is necessary to obtain relative measurements of the gas production in cropped and uncropped soils. For if less gas is produced in cropped land than in uncropped land, then the production of Methane is being interfered with and possibly that of Nitrogen also. On the other hand, if the gas production is greater in the cropped field, then, under the influence of the crop, Nitrogen is certainly being evolved. Again, if it is assumed that the volume of Methane evolved is the same in both cases, the effect of the crop is to bring about a great disengagement of Nitrogen, whereas, if the volume of Nitrogen is assumed to be the same, the crop prevents the formation of Methane. From whatever standpoint the analytical data are considered, there can be no doubt of the close relationship of the crop with the course of the soil fermentations and the necessity of obtaining some quantitative data becomes of vital importance to a proper understanding of the changes involved.

Unfortunately, this is not so simple a matter as it would appear. The obvious method is to support large funnels over the surface of the soil and to measure and analyse the evolved gases at intervals. When this is done, none of the soil gases are collected but, instead, there appears a gas consisting of entirely Oxygen and Nitrogen, and the volume collected is so great that its main source is obviously from the air or surface water. Under these circumstances, the direct collection of the soil gases by means of inverted funnels fails and recourse must be had, at least in the field, to indirect methods of measurement. This evolution of Oxygen was traced to a film of organized growth spread over the surface of the soil and its relationship to the growth of the plant is considered in the second part of the Memoir.

The usual method employed in these experiments for the collection of the soil gases is capable of giving approximately relative values for the amount of gas accumulated within the soil. On

walking through a field the gas is disturbed and escapes and the amount escaping in a given length will be proportionate to the amount of gas in the soil. Consequently, if the same collecting apparatus is carried the same distance through two fields, the amount collected will be in proportion to the amount of gas in the soils and a relative measurement is obtained.

Applying this method to the cropped and uncropped manured plots previously referred to, the following results are arrived at:—

TABLE VII

Showing the relative amounts of gas collected in traversing the same distance in cropped and uncropped plots.

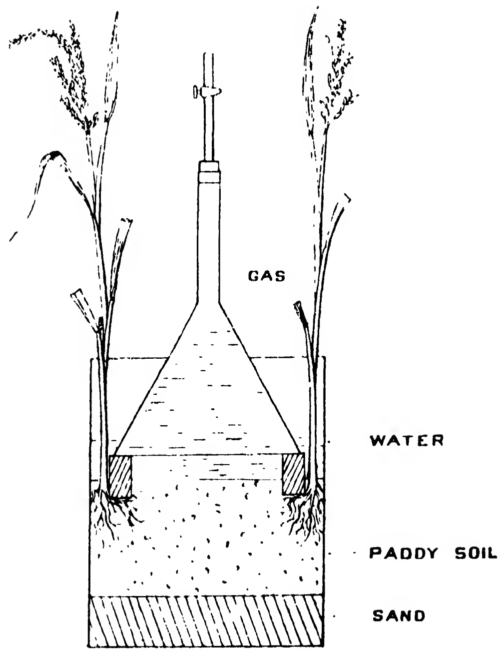
Date.	Ratio. = $\frac{\text{cc. from cropped field}}{\text{cc. from uncropped field.}}$
October 9th, 1911 .	3/2
,, 24th ,, .	11/10
,, 31st ,, .	3/4
November 13th ,, .	6/5

On the whole these results indicate that the accumulation of gas in cropped land is slightly greater than in uncropped soil. Such rough experiments as these can only be approximate, and it is unwise to draw stringent conclusions from them with reference to the numerical relationship of the volume of gas present in the soil. They can, however, be taken as indications, and justify the conclusion that there is no evidence to show that there is less gas present in the cropped plot; on the other hand, the quantities approximate to equality.

These conclusions apply only to the gases accumulated in the soil but, considering the type and intensity of the fermentation taking place, there must be large quantities of gas escaping through the surface, and the total volume of gas produced, may, in reality, be very dissimilar. The escaping gases are masked and probably profoundly modified in composition through the influence of the surface film previously referred to, and certainly under field condi-

tions no Methane or Carbon-dioxide was detected in the escaping gas. It was found by experiments in pots that this surface film could be prevented from forming by the use of a solution of copper sulphate of the strength of 1 : 250,000, and that when this was done the soil gases passed through the surface of the soil and could be collected and analysed. The strength of copper sulphate used had no detrimental effect on the growth of the crop, and accordingly a series of pot culture experiments were laid down, with the object of measuring the rates of evolution of the gases in cropped and uncropped pots and also of studying the effect of the crop on the composition of the gas.

The pots used were 18 inches deep and 14 inches diameter and had a layer of sand on the bottom 6 inches in thickness. Above this was placed a layer of soil weighing 40 kilos, to which was added green-manure at the rate of 5,000 lbs. per acre. A large inverted funnel 12 inches diameter and with the exit closed with a glass stop-cock was supported by small teak-wood blocks above the soil so that there was a space of half an inch between the rim of the funnel and the soil. The seedlings were arranged in the space between the funnel and the pot, and a depth of water was always maintained in the pot, sufficient to prevent air entering the funnel. The whole arrangement is sketched below.



No drainage was arranged for in these experiments as it was thought advisable to eliminate any conditions which might permit of the copper sulphate entering the soil and so interfering with the course of the

fermentation. In addition, parallel series of unmanured pots were instituted in order to obtain comparisons.

The main difficulty experienced was in preventing the evolution of Oxygen and Nitrogen from traces of the surface film and in fact it cannot be said that this was successfully done with reference to any one pot throughout the whole course of the experiment. When, however, Oxygen was found to be evolved by a pot the addition of copper sulphate at once stopped its further evolution and, as the duplicate pots rarely evolved Oxygen at the same time. it is possible to trace with fair accuracy the rate of evolution of the soil gases.

The gas evolved consisted mainly of Nitrogen with varying amounts of Methane and, for the purposes of comparison, it will be best to consider the latter first, as the contamination arising from the gases evolved from the undestroyed traces of the surface film does not materially affect the results.

The results obtained are tabulated below, and are given up to the date when the grains were fully developed and when the soil would be drained for ripening in the ordinary course of events.

TABLE VIII.

Showing the Methane production in c.c. from cropped and uncropped manured pots.

Date.		Cropped pots.			Uncropped pots.		
		Pot 1.	Pot 2.	Total.	Pot 3.	Pot 4.	Total.
First period.	8th to 18th January 1913 . .	8·0	1·5	9·5	*Nil.*	4·2	4·2
	18th to 30th January 1913 . . .	6·9	2·1	9·0	2·5	8·4	10·9
	30th January to 12th February 1913 .	4·4	4·6	9·0	4·0	8·6	12·6
	TOTAL .	19·3	8·2	27·5	6·5	21·2	27·7

Seedling transplanted into Cropped Pot on February 13th and the collection of gases recommenced February 24th.

Date.		Cropped pots.			Uncropped pots.		
		Pot 1.	Pot 2.	Total.	Pot 3.	Pot 4.	Total.
Second period.	24th February to 7th March 1913 . .	*Nil.*	*Nil.*	*Nil.*	8·5	8·7	17·2
	7th to 19th March 1913 . .	"	"	"	*Nil.*	10·7	10·7
	19th to 29th March 1913. . .	"	"	"	12·6	13·4	26·0
	29th March to 9th April 1913 . .	"	"	"	4·5	10·5	15·0
	9th to 21st April 1913	"	"	"	4·7	9·0	13·7
	Total.	*Nil*	*Nil*	*Nil*	30·3	52·3	82·6

The seedlings were not transplanted until February 13th, but before this date the gases were collected from all the pots and in every case Methane was evolved showing that the fermentation was established. After transplanting, Methane continued to be evolved from the uncropped pots, but none was obtained from the cropped ones. This is in entire agreement with the variations in the composition of the soil gases in the field experiments and it is evident that the crop prevents, in some way or other, the normal production of Methane.

During the same period the Methane evolution from the unmanured pots was very small, the uncropped pots only giving $\frac{1}{7}$ of the volume of the gas evolved from the corresponding manured pots, and at the same time practically no difference could be detected in the evolution from cropped and uncropped unmanured pots. This is in general agreement with the results from the unmanured experimental plots, and it is therefore evident that the Methane evolved from paddy soils is mainly derived from the green-manure and the effect of the crop in altering the composition of the soil gases would, therefore, appear to be due to its relationship to the course of the decomposition of the green-manure. Further, the action of the crop during the growing season is to diminish considerably the production of Methane and Hydrogen.

With regard to the Nitrogen evolution from these pots the results clearly show that much less Nitrogen is evolved from cropped than uncropped pots :—

TABLE IX.

Showing the total evolution of Nitrogen in c.c. from cropped and uncropped pots from the time of transplanting up to the time of heading (February 24th to April 21st, 1913).

	Manured.	Unmanured.
Cropped pots	220	212
Uncropped pots	453	471
Percentage decrease due to crop	51%	55%

These results are surprising in many ways. There can, of course, be no doubt as to the effect of the crop in reducing the quantity evolved, but the large production of gas compared to the volume of Methane evolved, and the similarity of the results between the manured and unmanured pots, point strongly to the conclusion that a large proportion of this Nitrogen is not derived from the soil gases.

That its evolution is not due to the action of the surface film is shown on page 95, where the action of copper sulphate in inhibiting the effect of the film is shown, and further support to this view is given by the fact that a manured pot treated with copper sulphate only gave off 105 c.c. of Nitrogen, whereas, a similar untreated pot yielded 445 c.c. from February 24th to April 21st.

Thus, it would appear that there is a surface evolution of nitrogen, unconnected with the soil fermentation or the surface film, due to some undiscovered cause which is affected by the growth of the crop. This being the case, these pot experiments have failed to give any indication of the source of the Nitrogen in the soil and the effect of the crop on the quantity present, but the field measurements throw some light on the problem.

The source of the Gaseous Nitrogen in the soil.

The determination of the origin of the soil Nitrogen is of importance and further experiments are being carried out to determine this point with some degree of certainty. This Nitrogen can only come from three sources :—

(1) The air imprisoned in the soil by the water.

(2) The Nitrogen dissolved in the irrigation water which penetrates the soil.

(3) The Nitrogen contained in the organic matter of the soil and manure.

There is no doubt that some of the soil Nitrogen is obtained from the sources indicated in (1) and (2), but a consideration of the amounts of gas obtained from the manured and unmanured plots in the field experiments leads to the conclusion that the larger proportion is derived from the Nitrogen present in the organic manure.

The gases collected by traversing the same distance in each plot were measured and analysed and the relative amounts of Nitrogen obtained are contrasted in the following table in the form of ratios. The ratio between the uncropped *manured* plot and the uncropped *unmanured* plot is referred to as Ratio = UM/UU and that between the corresponding cropped plots as Ratio = CM/CU.

TABLE X.

Showing the relative amounts of Nitrogen present in the manured and unmanured plots.

Date.	Ratio $=\frac{UM}{UU}$	Ratio $=\frac{CM}{CU}$
October 9th, 1911	1·5/1	2·3/1
,, 24th ,, ...	2·6/1	4·3/1
,, 31st ,, ...	3/1	2·6/1
November 6th ,, ...	1·6/1	2·1/1
,, 13th ,, ...	3·5/1	2·5/1

As the plots contrasted in the above table formed a portion of one small field, they were similar in every respect, with the exception

of the addition of green-manure. Consequently, if the whole of the Nitrogen in the soil came only from the air originally in the soil or from the Nitrogen dissolved in the water draining through it, it would be expected that the ratios would approximate to unity. Instead of this, on the average, about $2\frac{1}{2}$ times as much gas is present in the manured plots as in the unmanured plots, and the only obvious conclusion is that much of the soil Nitrogen is derived from the manure used and the organic matter present in the soil. This conclusion, taken in conjunction with the fact that less Nitrogen is evolved from cropped pots than uncropped pots, after treatment with the copper sulphate, supports the view that some Nitrogen is absorbed by the plant which otherwise would be evolved as gas in an uncropped field. The evidence is not as clear as we would wish and experiments are being carried out to test the question of this Nitrogen absorption in a more rigorous manner.

Mode of action of the crop in altering the composition of the Soil Gases.

It has been shown clearly that the normal evolution of Methane in paddy soil is greatly reduced in amount when a crop is introduced, and there are indications to show that the same probably occurs with the Nitrogen evolution. This being so, a wide field of investigation is opened out to determine the manner in which this action is brought about. It is clear that the crop is the primary cause, but the action may be indirect in the sense that substances may be excreted by the roots which inhibit or retard certain of the phases of the normal fermentation, or it may be direct in the sense that the plant is absorbing some of the decomposition products of the fermentation, thus removing them from the field of action and reducing the intensity of the action by that amount.

With regard to the first possibility, if the effect of the excreted substance were only transitory, it would appear that, when the crop reached full growth, the excretion would be arrested and the course of the normal fermentation re-established, resulting in an increased gas production. Evidence supporting this was obtained in the pot culture experiments for, when the crop reached the

ripening stage such an evolution occurred both with regard to Nitrogen and Methane as is shown in the following table:—

TABLE XI.

Showing the increased evolution of Gas when the ripening stage is reached.

Total gas evolution in cc.

DATE.	CROPPED POTS.		UNCROPPED POTS.		REMARKS.
	CH_4	N	CH_4	N	
9th to 21st April 1913	*Nil.*	77·3	13·7	58·4	
21st to 28th April 1913	24·1	52·5	6·6	32·6	Ripening stage reached about 21st April.
28th April to 5th May 1913	34·7	31·4	5·3	37·7	
5th to 13th May 1913	17·3	14·9	3·6	25·6	
Total cc. from 21st April to 13th May 1913	76·1	98·8	15·5	95·9	

Thus once the stage of ripening is reached, we find the cropped pots commencing to evolve Methane in considerable quantities, whereas, previously no Methane was given off. There is also a very large evolution of Nitrogen, and at the same time, the amount of Oxygen present in the evolved gas was very little, only amounting to a few cc., showing the effect of the surface film to be very small. These observations would seem to lead to the view that the effect of the crop is to retard the normal fermentation and some support is given by the behaviour of the unmanured pots. The cropped pots of the latter series showed only a comparatively small increased rate of evolution of Methane and Nitrogen such as would be expected, considering the absence of green-manure and with only the soil organic matter present.

A certain proportion of this evolution of gas in manured pots when the ripening stage is reached may possibly be due to the decomposition of the roots of the crop and not to decomposition of the green-manure recommencing. If this is proved to be the case, the possibility of the changes being due to the absorption by the

roots assumes greater importance. The possibility of the plant absorbing some of the organic compounds produced during certain phases of the fermentation is quite probable in view of the results of recent investigation on the assimilation of organic Nitrogen by the roots of plants. Hutchinson and Miller* working under sterile conditions have shown that certain plants can utilize the Nitrogen contained in such compounds as acetamide, urea, barbituric acid, alloxan, and to a lesser degree in formamide, glycocoll, oxamide, etc. Schreiner and Skinner† have since experimented with a large number of nitrogenous organic compounds and have come to the conclusion that the plant can absorb them *as such* and that certain of them are utilized by the plant in an advantageous manner, whilst others exert a toxic influence.

Among the substances experimented with by Schreiner and Skinner were many of the compounds produced by the decomposition of proteids and it is just these compounds which would be produced in paddy soils when the green-manure is decomposed. Consequently, if their view is correct, these substances would be absorbed by the paddy roots and the normal fermentation would be lessened in proportion, thus tending to produce a change in the composition of the soil gases.

The whole subject of the relationship of the paddy crop to the soil fermentations is of great importance and is under further investigation.

The Anærobic conditions of the soil in relation to Nitrogen assimilation.

Apart from the question of the relation of the crop to the composition of the soil gases it is evident that the strongly anaerobic conditions prevailing in these swamp paddy soils have a direct bearing on the course of the Nitrogen assimilation of the plant as ordinarily understood. Since Kellner‡ in 1882 showed with swamp

* Cent. F. Bakt. 30-513 (1911).
† U. S. A. Department of Agriculture Soil Bureau Bull. No. 87, 1912.
‡ Landw. Vers. Station 30 (1884).

paddy that Ammonium salts are more effective as a manure than Nitrates, many investigations have been carried out and the consensus of opinion appears to be strongly against the utility of the latter class of substances, although, possibly with certain varieties of paddy and under certain cultural conditions, Nitrates may be very effective when the plant is heading or approaching ripeness. In recent years Daikuhara and Imasiki,* in Japan, have shown that denitrification takes place very rapidly in these soils leading to loss of Nitrogen and to the formation of toxic Nitrites. They also showed that Ammonium salts are quite suitable as manures, and that the crop absorbed them as such. Kelly† in Hawaii has confirmed these results and, moreover, showed that Nitrates are not readily absorbed by paddy plants. It may, therefore, be accepted that Nitrates do not persist in these soils, that they are not properly absorbed by the crop, and that poisonous Nitrites are produced from them. Nitrates and Ammonium salts are not used by the South Indian cultivators, but still a knowledge of the behaviour of such substances is of importance, as they are both produced in local soils at one time or another during the season.

These swamp paddy soils are exceedingly clayey in character, and, during the dry season, are fissured in all directions by deep cracks by which air freely enters and thoroughly aerates the soil. Under these conditions nitrification proceeds, and although the crop of weeds, annually raised at this time, must assimilate a great proportion of the produced Nitrates, yet, in the aggregate there must be a considerable quantity of Nitrate present in the soil when the water is admitted for the ensuing paddy crop. The rate at which this Nitrate disappears must depend greatly on circumstances. If the amount of Oxygen imprisoned in the soil is large, or if it persists for some time, or if the fermentation of the green-manure is slow in the earlier stages, this Nitrate may remain undecomposed for some time and have some effect on the crop in the earlier stages just after transplanting.

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* Bull. Imp. Cent. Agri. Exptl. Stn., Japan, Vol. 1, No. 2.

† Bull., 24, Hawaii Agri. Exptl. Stn.

The analysis of the soil gases immediately after water is admitted to the field does not, however, support this view, for on July 27th, 1909, within a very few days after the time of admitting water to the experimental plot, very little gas was present and what there was consisted of 53·4 per cent. Nitrogen, 39·4 per cent. Methane and only ·8 per cent. Oxygen. Further, in 1912, the first samples of gas obtained from the four experimental plots contained from 88·5 to 93·6 per cent. N, 5·8 to 7·1 per cent. CO_2 and only ·6 to 4·4 per cent. Oxygen. Thus it is evident that the anaerobic condition of these soils commences from the date of the first admission of water, long before the crop is introduced into them. Consequently, the Nitrate formed during the dry season is quickly denitrified and is of no value so far as the cultivator is concerned. Neither, in view of the composition of the soil gases and the presence of a large amount of decomposing organic matter in the shape of ploughed-in weeds and green-manure, is the occurrence of nitrification during the growing season probable and the crop must as a consequence derive its necessary Nitrogen from the products of the putrefaction of the proteids present in the green-manure.

It is this aspect of the case which is of importance to the South Indian agriculturalist, and it is one worthy of detailed study. The putrefactive decomposition of green-manure which occurs in these soils leads to the production of a number of substances. The carbohydrates are vigorously attacked under anaerobic conditions and the proteids are decomposed with the formation of albumoses, peptones amine bases, volatile acids of the fatty series, acetic acid, succinic acids, skatol, indol, phenol, ammonia, carbon-dioxide and many other substances. Methane is also produced, according to Omelianski by a special ferment which attacks cellulose, but of which, the authors have discovered no trace in the soils examined. The Ammonia and many of the nitrogenous substances produced are absorbed by the plant and utilized in the formation of tissue and consequently the general suitability of nitrogenous manures for paddy may be stated as follows :—

Manures which contain Ammonia or which yield Ammonia and comparatively simple nitrogenous organic substances on anaerobic decomposition, are suitable manures, whereas Nitrates are not suitable for swamp paddy.

Schreiner and Skinner have shown that not all of these substances are beneficial to the crop. Certain of them appear to be directly assimilated by the crop and are utilized in the formation of tissue, but others have been shown to be toxic and to injure the cropping. Field results in the Tanjore Delta* show clearly the injurious result which may arise from the application of green-manure to badly drained soils into which young and tender seedlings are transplanted, and there can be no doubt that the beneficial aspect of drainage in relation to swamp paddy soils is partly concerned in the removal of these toxins from the soil. The aspect of drainage to paddy is, however, considered more in detail in the second part of this Memoir.

In localities where the lack of drainage does not permit of the removal of these toxins in the manner indicated, the same end might possibly be achieved by ploughing-in the green-manure several weeks before the time of transplanting, so that some considerable amount of decomposition will have proceeded by the time the young seedlings are introduced. Brieger has observed that the poisonous substances produced during the putrefaction of proteids are only formed in the early stages and that they disappear on prolonged decomposition. It appears therefore probable that the method outlined above would lead to a considerable destruction of the toxins, by the time the seedlings were transplanted.

Summary to Part I.

The conclusions arrived at may be summarized as follows:—

(1) The normal fermentation of green-manure in swamp paddy soils leads to the production of a relatively large proportion of Methane, a smaller amount of Nitrogen, together with some Carbon-dioxide and Hydrogen.

* H. C. Sampson's Annual Report of the Manganallur Agri. Station, 1912-13.

(2) The introduction of a crop so modifies the gas production that the proportion of Methane in the gas is greatly reduced and that of Nitrogen increased. The evolution of Hydrogen is practically inhibited.

(3) The action of the crop is to restrict the formation of Methane and Hydrogen either by retarding the rate of fermentation or by a portion of the intermediate products of decomposition being absorbed by the roots. There is also evidence adduced to show that the normal evolution of Nitrogen is retarded in a similar manner.

(4) The soil conditions are shown to be anaerobic in character immediately after water is admitted to the fields, and these conditions persist so long as irrigation proceeds. Under these circumstances, nitrification is impossible and the Nitrates produced during the dry season are quickly denitrified so that the Nitrogen required by the crop is obtained from the Ammonia and nitrogenous organic compounds produced by the anaerobic decomposition of the proteids of the green-manure.

(5) Certain of the substances produced by this decomposition are toxic to the crop, and must be removed in the drainage water, or destroyed by prolonged decomposition before the seedlings are transplanted, otherwise the crop will suffer. The application of green-manure to badly drained areas must, therefore, be undertaken with circumspection and caution.

PART II.

The Gases evolved from the surface of Paddy Soils.

In the foregoing section of this Memoir attention has been called to the fact that the gases present in the soil itself are dissimilar in composition from the gases which are evolved from the surface of swamp paddy soils. The latter consists mainly of Oxygen and Nitrogen, and we have not been able to detect the presence of Methane, Hydrogen and Carbon-dioxide in them. The last mentioned gases are characteristic constituents of the soil gases and as a consequence there did not appear to be any connection between the soil gases and the surface gases. That there was some relationship, however, between the rate of evolution of Oxygen and the presence or absence of a crop was indicated by a number of haphazard determinations made during the year 1909 and consequently, at the earliest opportunity, some pot-culture experiments were instituted to test this point.

Two pots were taken each 12 inches diameter and 12 inches high with a layer of sand 3 inches deep at the bottom. Over this was placed a layer of paddy soil 5½ inches thick, thus allowing a depth of 3½ inches for the surface water. An arrangement for draining the pots was introduced, which consisted of an inverted funnel embedded in the sand layer with its shank connected to a syphon discharging through a tubulure in the bottom of the pot, and the exit of which was closed by means of a rubber tube and pinch-cock. Each pot received green-manure at the rate of 10,000 lbs. to the acre, which was well puddled into the soil, and a certain amount of water was drained off each week, not sufficient, however, to expose the base of the inverted collecting funnels placed above the soil, and so allow air to enter. Paddy was transplanted into one pot on December 21st, 1911, and the other pot remained uncropped.

The gases evolved consisted usually only of oxygen and nitrogen, but in the later stages, a small amount of Methane was sometimes present.

The following table shows the collection of oxygen in cc. :—

TABLE I.

Showing the rate of collection of Oxygen in cc. from the cropped and uncropped pots.

DATE.	CROPPED POT.		UNCROPPED POT.		Daily excess of Oxygen given off from the uncropped pot + or −
	cc. O	Daily rate.	cc. O	Daily rate.	
31st December 1911 to 6th January 1912	63	10·5	204	34·0	+ 23·5
6th to 12th January 1912	130	21·6	241	40·0	+ 18·4
12th „ 19th „ „	191	27·2	234	33·4	+ 6·2
19th „ 26th „ „	244	34·9	183	26·1	− 8·8
26th January to 7th February 1912	315	28·6	542	49·2	+ 20·6
7th to 21st February 1912	584	41·7	738	52·7	+ 11·0
21st February to 5th March 1912	568	43·7	833	64·0	+ 20·3
Total and average	2,095	average 32·2	2,975	average 45·7	average + 13·5

It is evident that in this experiment the effect of the crop was to lessen the evolution of Oxygen by 880 cc. or equal to 13·5 cc. per day on the average. It is also evident that the absorption of Oxygen is not uniform throughout the period, but that it took place in two stages. A reference to the last column of the table will show this, where the daily excess of Oxygen evolved from the uncropped pot is given. From December 31st to January 19th the daily excess gradually diminishes until, between January 19th and February 7th, there is more Oxygen evolved from the cropped than the uncropped pot. Afterwards there is an excess of Oxygen evolved from the uncropped up to the end of the experiment.

These results were so definite that it was decided to lay down a more extensive series of experiments and, accordingly, two series were started early in 1913. The two series were parallel experiments and differed from each other only in the depth of the pots

and the size of the collecting funnel. Each series consisted of cropped and uncropped manured pots and similar unmanured pots.

In Series I the pots were 18 inches high and 14 inches diameter with a layer of sand 6 inches thick on the bottom and above this 40 kilos of soil. The gas collecting funnel was 10 inches diameter. Series II consisted of pots 16 inches high and 12 inches diameter with a 6 inches layer of sand and 20 kilos of soil. The funnel in this case was only 8 inches diameter. To the manured pots green-manure was added at the rate of 5,000 lbs. per acre.

All the pots were undrained, thus differing from the previous experiment. The seedlings were introduced on February 12th, but the gases were not collected until the seedlings were established on February 24th.

The results are tabulated below :—

TABLE II.

Showing the Oxygen evolution from the pots of Series I.

Date.	Manured Pots.					Unmanured Pots.				
	Cropped.		Uncropped.		Daily excess of Oxygen from cropped pots + or −	Cropped.		Uncropped.		Daily excess of Oxygen from cropped pots + or —
	cc. O	Daily rate cc.	cc. O	Daily rate cc.		cc. O	Daily rate cc.	cc. O	Daily rate cc.	
24th Feby. to 3rd March 1913	2·3	·33	2·4	·34	− ·01	14·9	2·12	1·5	·21	− 1·91
3rd March to 10th March 1913	2·4	·34	26·3	3·75	+3·41	14·8	2·11	2·0	·28	1·83
10th March to 17th March 1913	9·1	1·30	56·4	8·05	+6·75	1·9	·27	15·4	2·20	+1·93
17th March to 28th March 1913	14·9	1·35	65·5	5·95	+4·60	1·2	·24	43·1	3·91	+3·67
28th March to 4th April 1913	13·5	1·92	31·2	4·45	+2·53	1·4	·20	28·0	4·00	+3·80
4th to 11th April 1913	20·0	2·85	23·1	3·30	+·45	1·5	·21	38·6	5·51	+5·30
11th to 17th April 1913	15·3	2·55	26·7	4·45	+1·90	·7	·10	30·4	5·06	+4·96
17th to 23rd April 1913	16·3	2·71	44·4	7·40	+4·69	1·1	·18	19·9	3·31	+3·13
23rd to 30th April 1913	51·2	7·31	17·3	2·47	− 4·84	2·4	·34	12·8	1·82	+1·48
30th April to 7th May 1913	54·3	7·75	29·3	4·18	− 3·57	11·4	1·62	7·7	1·10	− 1·52
Total and average	199·3	2·76	322·6	4·48	+1·72	51·3	·74	199·4	2·77	+2·03

Table III.

Showing Oxygen evolution from the pots in Series II.

Date.	Manured Pots. Cropped. cc. O		Manured Pots. Uncropped. cc. O		Daily excess of oxygen from uncropped pot + or −	Unmanured Pots. Cropped. cc. O		Unmanured Pots. Uncropped. cc. O		Daily excess of oxygen from uncropped pot + or —
		Daily rate cc.		Daily rate cc.			Daily rate cc.		Daily rate cc.	
24th Feby. to 3rd March 1913 .	3·3	·47	61·2	8·74	+8·27	5·4	·77	7·8	1·11	+ ·34
3rd to 10th March 1913 . .	2·6	·37	43·5	6·21	5·84	1·5	·21	18·9	2·70	+ 2·49
10th to 17th March 1913 . .	1·2	·17	63·3	9·04	8·87	2·0	·28	39·8	5·68	+ 5·40
17th to 28th March 1913 . .	1·1	·10	107·4	9·76	+9·60	·5	·04	125·3	11·39	+ 11·35
28th March to 4th April 1913. .	5·1	·72	45·5	6·50	+5·78	·4	·05	39·0	5·57	+ 5·52
4th to 11th April 1913 . .	6·9	·98	75·6	10·80	+9·82	1·1	·15	65·2	9·31	+ 9·16
11th to 17th April 1913 . .	7·0	1·16	68·2	11·36	10·20	3·1	·52	59·0	9·83	+ 9·31
17th to 23rd April 1913 . .	3·4	·56	48·6	8·10	+ 7·54	10·1	1·68	31·7	5·28	+ 3·60
23rd to 30th April 1913 . .	3·8	·54	35·7	5·10	+4·56	9·2	1·31	22·8	3·25	+ 1·94
30th April to 7th May 1913 . .	3·5	·50	25·2	3·60	3·10	7·6	1·08	27·0	3·85	2·77
		Average.		Average.	Average.		Average.		Average.	Average.
Total and average	37·9	·52	574·2	7·97	7·45	40·3	·56	436·5	6·06	+ 5·50

These results, like those of the earlier experiment, show a much less evolution of Oxygen from the cropped pots than from the uncropped ones. The smaller evolution of Oxygen from the cropped pots only continues during the active growing period, for, as soon as the ripening stage is reached (about April 23rd) an increased evolution occurs, and in fact, in the first series more Oxygen is evolved than from the corresponding uncropped pots.

The difference between the rates of evolution of cropped and uncropped pots is shown in the above table and this may be looked upon as measuring an absorption of Oxygen by the crop. With the exception of the unmanured pots of Series No. I there is a sudden decrease in the rate of absorption about the first week of April, just before the crop headed and it would, therefore, appear as if the

growth of paddy took place in two stages. What bearing this has on manurial and cultural problems is not quite clear; but it is interesting to note that around Palghat, it is customary, on certain types of soil, to manure the crop at half growth. The authors are under the impression that a similar procedure is customary with certain Chinese cultivators of paddy.

The smaller evolution of Oxygen from the cropped pots and its relation to the stage of growth of the plant implied some connection between the life of the crop and the production of Oxygen at the surface of the soil. At this stage our colleague Dr. C. A. Barber very generously placed before us the results of his examination of paddy roots of different types which led him to the conclusion that these roots are not typical water plant roots, as would be expected, but that they are similar to the roots of ordinary dry land crops and, as such, they would require aeration if their healthiness is to be maintained. It was, therefore, concluded that the Oxygen evolved at the surface of the soil was utilized by the plant for the purpose of aeration of the roots.

The cause of this evolution was traced by us to a film of organized growth spread over the surface of the soil which varies considerably in character in different localities. Algæ of various kinds are usually present in considerable quantity, but occasionally films are obtained which are practically devoid of such growths. Diatoms are invariably present, occasionally to such an extent as to produce a friable white skin over the surface of the dried off soil, which has been mistaken for a saline incrustation. Apart from these organisms, there appears to be a constituent of the film of a bacterial nature. During the progress of the pot culture experiments a film grew up the interior of the funnels, which was slightly brown in colour, due to the presence of diatoms and earthy particles, but which contained no green algæ. Under the microscope it was found to consist of irregular filaments which show no definite structure and which are covered with bacteria, the latter being arranged with their long axis parallel to the direction of the filament. Occasionally films are obtained from the fields which

contain a very small proportion of algal growth and which appear to consist almost entirely of this unorganized filamentous growth together with diatoms.

In Plate II, Fig. 1 shows the general character of this film and Fig. 2 a single filament magnified 1,000 diameters.

The function of this latter growth is at present undetermined. Considering the facts that (1) we have not been able in the field to demonstrate the presence of gaseous Carbon compounds in the surface gases, and (2) the amount of Oxygen evolved from a field is increased by the presence of green-manure in the soil (page 104), it would appear possible that this growth brings about a change in the carbon constituents of the soil gases such as to make them available as food for the green algæ. Support is given to this by the fact that we have been able to isolate cellulose, or some closely related substance, from films which contained no green algæ or organised growths other than diatoms.

These observations, which led us to the conclusion that the aeration of the roots is largely due to the agency of the surface film, practically supplement and confirm the work of Brizi,* in Italy, work to which our attention has only recently been called. Brizi states that the roots of the rice plant do not conform to the aquatic type and showed, by means of water cultures, that aeration was absolutely essential for their growth. He also showed that the introduction of algæ, obtained from rice fields, into cultures devoid of Oxygen, but in which Carbon-dioxide was present, was sufficient to thoroughly aerate the roots and promote healthy growth. This was due to the algæ assimilating the Carbon-dioxide and liberating Oxygen. His experiments led him to the conclusion that the presence of algæ in rice fields must largely increase the quantity of dissolved Oxygen in the irrigation water and lead to the efficient aeration of the roots. His work, taken in conjunction with our measurements, shows clearly the importance of the surface growth to the crop. In the best examples of this surface film, it is

* Annuario Dell Instituzione Agraria Dott. A. Ponti, Vols. V, VI and VII, 1905-06 and '08.

PLATE II.

Fig. 1

Fig. 2

thick and tenacious and practically continuous over the surface of the field. Between it and the soil surface accumulate large bubbles of gas which on analysis rarely contained less than 50 per cent. Oxygen, so that under normal conditions there is an atmosphere very rich in Oxygen in contact with the soil and capable of strongly aerating any water passing into the soil or water already present in the soil and in contact with the Oxygen.

Reference has been made to the fact that the surface gases evolved from paddy soils consist not only of Oxygen, but contain large quantities of Nitrogen as well, and the connection between the two is shown by the fact that applications of copper sulphate greatly reduce the evolution of Nitrogen just in the same way that the Oxygen evolution is inhibited. This is well shown in the following table which gives the results from a typical experiment.

TABLE IV.

Showing effect of Copper sulphate in inhibiting the evolution of the Surface Gases.

DATE.	cc. O.	Daily rate in cc.	cc. N.	Daily rate in cc.	REMARKS.
23rd December 1912 to 3rd January 1913	13·6	1·23	19·8	1·80	No copper sulphate present.
3rd to 7th January 1913	7·6	1·90	21·4	5·35	
7th to 18th January 1913	·5	·05	5·5	·55	
18th to 30th January 1913	·9	·07	9·0	·75	Copper sulphate present.
30th January to 12th February 1913	1·2	·09	9·6	·73	

It would appear that this Nitrogen is derived originally from the air and that its evolution is obviously connected with the presence or absence of a surface film. The analysis of the gases from cropped and uncropped pots also brings out clearly the fact that the amount of Nitrogen evolved depends upon the presence or absence of a crop and varies approximately with the amount of Oxygen evolved from any one pot. The cropped pots give off less Nitrogen than the uncropped pots, and the difference between the volumes

shows in a general way the same variations as those of the Oxygen evolution.

The evolution of Nitrogen would, therefore, appear to be dependent upon that of Oxygen, thus pointing to its being a purely physical phenomenon. The Oxygen evolved is the residue of the Oxygen produced by the surface film which has escaped absorption by the roots and collects, as we have shown, in bubbles under the film. The green algal growths give off practically pure Oxygen, so that, in the first instance, bubbles of pure Oxygen will collect. Surrounding these bubbles is water containing amounts of Oxygen and Nitrogen in solution proportionate to their partial pressures in the atmosphere, but at the point of contact with the bubble the partial pressure of Oxygen becomes relatively high and that of Nitrogen low; consequently there is a tendency for Oxygen from the bubble to go into solution and nitrogen to come from the water to its place. This action will go on until equilibrium occurs and the bubble of gas will no longer consist of pure Oxygen but a mixture of the two gases.

The greater the amount of Oxygen collecting at the surface of the soil the greater will be the quantity of Nitrogen evolved. Thus the rate of the Nitrogen evolution from the pots will follow generally that for the Oxygen.

The effect of the Drainage and Aeration of the soil on the crop.

On considering carefully the results of our observations on the relationship of the evolution of Oxygen to the aeration of the roots, it was clear to us that the drainage of paddy soils must be an important factor with regard to the amount of aeration produced in them. In undrained soils the aerated water at the surface of the soil could not possibly enter the soil and consequently, aeration would be restricted to the surface layers of soil. On the other hand, drainage would cause the aerated surface water to penetrate into the soil and aeration would be deeper. This being so it appeared probable that the depth of aeratïon would be proportionate to the

rate of drainage, and the greater the rate of drainage the deeper would be the aeration of the soil with, probably, a proportionately increased cropping.

Again, as the aeration of the roots bears such an important relationship to the growth of the crop it appeared to us probable that the effectual aeration of the soil could be achieved with the expenditure of much less irrigation water than normal, by periodically draining the pots completely and thus permitting air to enter the soil. Further, this aeration of the soil would produce more aerobic conditions and there would be less danger of an excessive amount of toxic substances being produced. The conditions would also be more suitable for nitrification and this might have a favourable action on the growth.

Accordingly to test these points two separate experiments were instituted, one series to determine the effect of varying rates of drainage on the cropping, and the other to test the effect of aerating the soil by permitting the pots to drain thoroughly between consecutive irrigations.

The effect of Drainage on the crop.

In this experiment the pots were 12 inches in diameter and contained, on the bottom, a layer of sand weighing 10 kilos and above this a layer of 12 kilos of soil. 40 grammes of green-manure were added to each pot and drainage was provided for by means of an inverted funnel filled with sand, embedded in the sand layer and connected to a syphon discharging through the tubulure in the base of the pot. Continuous drainage was not given, but each pot, on the appointed date, was allowed to drain until the surface soil was nearly uncovered when the drainage was closed and fresh water added. The time elapsing between consecutive drainings varied from 1 to 7 days, but each pot received uniform treatment throughout the experiment. When the time of ripening approached, all the pots were drained and only kept moist until the harvest was taken. The same number of plants were present in each pot.

The results obtained are given in the following tables :—

Table V.

Showing the Grain Production.

Experiment.	Series I. Wt. of grain in gms.	Series I. Loss or increase.	Series I. Wt. of N. in gms.	Series II. Wt. of grain in gms.	Series II. Loss or increase.	Series II. Wt. of N. in gms.
Undrained	11·15	..	·094	12·15	..	·113
Drained every 7th day	13·47	+2·32	·107	13·80	+1·75	·121
,, ,, 3rd ,,	14·45	+3·30	·127	17·65	+5·50	·147
,, ,, 2nd ,,	11·92	+·77	·117	14·25	+2·10	·139
,, ,, day	12·08	+·93	·108	13·60	+1·45	·132

So far as the production of grain is concerned, it is at once evident that drainage exerts an exceedingly beneficial effect. At the same time, it is apparent that this effect is not in proportion to the amount of drainage, but that a maximum effect is produced with only a moderate amount. Excessive drainage reduces the yield to within measurable limits of the undrained pot. The amount of Nitrogen accumulated in the grain also shows the same variations.

Table VI.

Showing Straw and Chaff Production.

Experiment.	Series I. Wt. in gms.	Series I. Loss or increase.	Series I. Wt. of N. in gms.	Series II. Wt. in gms.	Series II. Loss or increase.	Series II. Wt. of N. in gms.
Undrained	24·70	..	·079	21·45	..	·072
Drained every 7th day	19·75	—4·95	·065	21·80	+·35	·071
,, ,, 3rd ,,	26·40	+1·70	·104	27·45	+6·00	·091
,, ,, 2nd ,,	20·57	—4·13	·067	26·10	+4·65	·092
,, ,, day	24·37	—·33	·039	26·00	+4·55	·060

Although the agreement between these two series is not good, yet, it is evident that the maximum production of straw is produced with drainage every 3rd day.

Consequently, it would appear that paddy requires only a moderate amount of drainage to enable the crop to produce its maximum yield, too much drainage being detrimental.

The effect of Aerating the Soil.

The pots in these experiments were 12 inches diameter and 17 inches high. 12 kilos of sand were placed on the bottom and over this a layer of 15 kilos of earth and drainage was arranged for as described in the previous experiment. 40 grammes of green-manure were puddled into the soil of each pot.

One pot remained undrained throughout the whole period and of the remaining pots a system of alternate swamping and draining was instituted. All the pots were allowed to remain covered with water for three days and then were allowed to drain for 1, 2, 4 or 8 days before being swamped again. The drainage was complete in each case, thus causing air to enter the soil, the object being to induce conditions more likely to cause nitrification than those normal to swamp soils and also to endeavour to obtain a relative measure of the values of dissolved Oxygen and gaseous Oxygen in aerating the roots.

The results are set forth in the following tables :—

TABLE VII.

Showing the effect of different periods of Soil Aeration on the Production of Grain.

Experiment.	Series I. Weight of grain.	Series I. Loss or increase.	Series I. Weight of Nitrogen.	Series II. Weight of grain.	Series II. Loss or increase.	Series II. Weight of Nitrogen.
Unaerated	14·58	..	·145	14·48	..	·147
Covered for 3 days and drained 1 day	16·30	+1·72	·175	15·89	+1·41	·164
Covered for 3 days and drained 2 days	16·60	+2·02	·186	14·36	-·12	·151
Covered for 3 days and drained 4 days	12·76	-1·82	·136	10·57	-3·91	·102
Covered for 3 days and drained 8 days	5·38	-9·20	·066	4·65	-9·83	·054

Thus, aeration of the soil has an effect which reaches a maximum at between one and two days' aeration, yielding on the average about a 10 per cent. increase, but longer aeration than this is very detrimental and the yields are much worse than those of the un-aerated pot.

TABLE VIII.

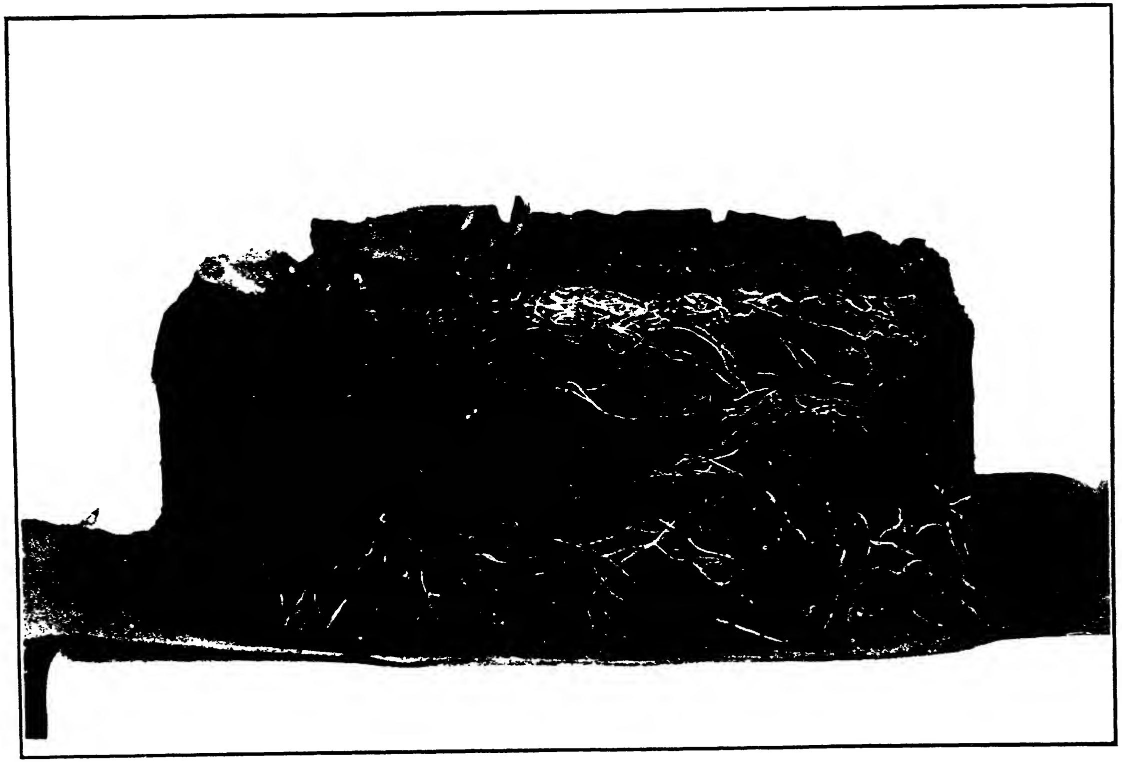
Showing the effect of different periods of Aeration on the Production of Straw and Chaff.

Experiment.	Series I.			Series II.		
	Weight of straw.	Loss or increase.	Weight of Nitrogen.	Weight of straw.	Loss or increase.	Weight of Nitrogen.
Unaerated	24·07	. .	·081	22·82	. .	·077
Covered for 3 days and drained 1 day	29·78	+5·71	·106	27·94	+5·12	·093
Covered for 3 days and drained 2 days	31·20	+7·13	·107	25·98	+3·16	·088
Covered for 3 days and drained 4 days	23·84	—·23	·105	20·88	—1·94	·088
Covered for 3 days and drained 8 days	12·97	—11·10	·056	12·62	—10·20	·068

The production of straw follows the same variations as that of grain, but in a more distinct manner as the maximum increase is about 20 per cent.

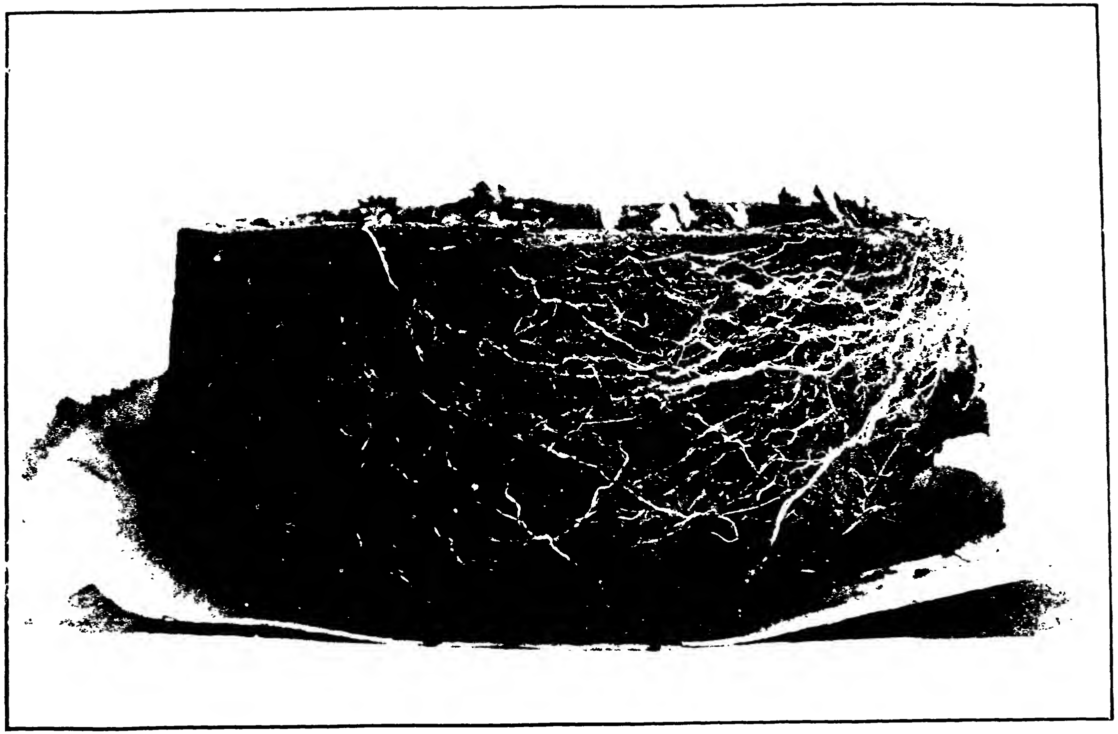
The conclusion is evident that a small amount of aeration leads to a somewhat heavier cropping, but the increase obtained, so far as grain is concerned, is not so marked as with simple drainage. It would therefore seem that the admission of air to the soil does not lead to as effective aeration as simple drainage. The explanation of this would appear to lie with the concentration of the dissolved Oxygen in the soil water. We have previously shown that the normal condition of paddy soils is such that the water entering the soil is very strongly aerated owing to its having been in contact with an atmosphere very rich in Oxygen, whereas the admission of air into the soil would yield a weaker solution approximately equal to that produced by contact with air and the aeration of the

PLATE III.



Root Development in *undrained* pot.

PLATE IV.



Root Development in *drained* pot.

roots would be proportionately less. The further conclusion may also be drawn that Oxygen to be effective must be presented to paddy roots in a state of solution.

One fact was very clear that the periods of aeration, if prolonged much over 24 hours, had the effect of preventing the formation of the surface film and thus the aeration of the roots during the period of swamping was not effective.

The effect of Drainage on the Root action of Paddy.

The action of moderate amounts of drainage in promoting increased cropping is obviously connected with the introduction of a greater amount of dissolved Oxygen into the soil. An examination of the root development in the drained and undrained pots showed that this increased aeration had led to a deeper and more extended root action. In the undrained pots the greater proportion of roots were distributed through the top layer of the soil at the point where aeration could only take place and consequently, the mass of soil from which they drew their substance, was restricted and the crop suffered as a consequence. On the other hand, in the drained pots the penetration of Oxygenated water into the depths of the soil had induced a deeper root development. This action of drainage is well shown in the photographs in Plates III & IV where the root development in undrained and drained pots is contrasted. Although, with a small amount of drainage there is a much deeper root development than in the undrained condition, yet, there does not appear to be a greater production of roots, for, the undrained pots yielded a total of 19·75 grammes of dried roots and the pots drained every third day 19·90 grammes. On the other hand, a quick rate of drainage reduces the amount of root produced, the pots drained every day only yielding 11·7 grammes.

These results of the drainage experiment are apparently conflicting. It would be expected that increased drainage would lead to increased aeration, by bringing larger volumes of aerated water in contact with the roots. Whereas, the maximum effect is

attained with a comparatively slow rate of drainage, and increased rates lead to reduced cropping and root development. The explanation lies in the fact that the quicker rates of drainage had the effect of decreasing the growth of the surface film and, as a matter of fact, no visible film formed in the pots drained every day. It is, therefore, apparent that quick drainage, by inhibiting the growth of the surface film and thus preventing the evolution of Oxygen at the surface of the soil, may actually lead to decreased aeration of the roots. *Thus, the most efficient rate of drainage is not the quickest, but that one which permits the film to maintain full activity.*

This being the case, the explanation of the universal custom of puddling these soils and so reducing the drainage through them is apparent. During the dry season the soils dry and shrink and their physical condition becomes coarser so that their rates of drainage would be increased. On puddling the soils when water is admitted the aggregate particles formed during the dry period are broken down and the soil returns to its original condition and rate of drainage. It is obvious that the amount of puddling given will affect the drainage in proportion and it would therefore appear that the ryot has at his command a simple method of regulating the latter, and as a consequence, the aeration of his soils.

The relation of drainage to aeration has also an important bearing on the formation of new paddy soil. Dry soils, even when of a heavy nature, do not yield their maximum crop of paddy at once when converted into wet lands. Usually, the yields of the first few years are exceedingly poor and it is only after several years have elapsed that such land is looked upon as even fair swamp paddy soil. Some investigations carried out by us several years ago led us to the conclusion that, in the first few years after paddy cultivation is initiated on land previously under dry cultivation, the main change taking place was a sorting of the particles between the soil and sub-soil, the coarser particles tending to accumulate in the sub-soil and *vice versa*. Afterwards, this action diminished and then it is

possible to demonstrate that, in both soil and sub-soil, the main effect of the cultivation is a breaking down of the soil particles, thus producing a heavier soil as years go on. Thus in these new soils the rate of drainage is continually tending to diminish and it is not until this rate permits the formation of the surface film that the maximum yields are obtained.

Hutchinson* has recently published an article dealing with relationship of drainage to rice soils showing that drainage is beneficial to the cropping which he ascribes to the removal by the drainage water of the toxins produced by the decomposing manure, and also to the possibility of the formation of Nitrates. There can be no doubt that one of the functions of drainage is the removal of noxious substances from the sphere of the activity of the roots, as we have pointed out in Part I, but we are unable to agree to his theory of Nitrate production.

In the first place, if the good effects of drainage were merely due to the removal of toxins and the formation of nitrates from the Oxygen dissolved in the water then, within reasonable limits, the quicker the drainage the better should be the results obtained. In our experiments the removal of water every second day cannot be looked upon as constituting an excessive rate of drainage, yet the results in cropping were very much worse than those produced by a slower rate of drainage.

Further the relation of Nitrates to well drained paddy soils has been studied by Kelly† in Hawaii who has shown that (1) denitrification is very rapid, (2) if Nitrates are present, poisonous Nitrites are produced and a concentration of the latter of only 5 parts per million of soil injures the crop, (3) rice seedlings are unable to assimilate Nitrates, and (4) Nitrates used as a manure show little or no effect and, in pot culture, stunt the growth. The evidence adduced

* Agri. J. India, Vol. VIII. Part 1, page 35. 1913.

† Loc. cit.

by Kelly goes to show that the formation of Nitrates in swamp paddy soils would not help the plant.

In addition, when it is taken into consideration that in our field experiments we only found traces of Oxygen in the soil gases, the possibility of Nitrate formation is very remote, especially in the presence of large quantities of decomposing green-manure. The drainage of the fields experimented with was quite good so far as paddy soils go.

The results of our aeration experiment would also appear to support the contention that Nitrates are not utilized by the plant, for, with admission of air to the soil, the fermentation of the green-manure would become more aerobic in character and the formation of toxic bodies reduced in amount, and, at the same time, the conditions would be more favourable to the production of Nitrates. The results, although showing some improvement with a slight amount of aeration, are not so good as those produced by simple drainage and in fact strong aeration leads to a decreased outturn.

The relationship of Green-manuring to the aeration of the Roots.

From the point of view of the South Indian cultivator the relationship of the green-manure, which he uses, to the aeration of the roots is of prime importance. Does the presence of this large quantity of organic matter in the soil tend to prevent efficient aeration of the roots or does it improve the aeration by increasing the activity of the surface film ?

In a previous paragraph we have discussed the relationship of the film to those constituents of the soil gases which contain Carbon and we have indicated the possibility that these substances are intercepted by the film and are utilized in such a way as to promote increased activity. If this is the case, it would be expected that the increased fermentation going on in the soil owing to the presence of

green-manure would lead to a greater production of Oxygen by the film. That this is the case is shown in the following table :—

TABLE IX.

Showing the production in cc. of Oxygen and Nitrogen in manured and unmanured uncropped pots from December 23rd, 1912, *to May 13th,* 1913.

	Series I.		Series II.	
	Oxygen cc.	Nitrogen cc.	Oxygen cc.	Nitrogen cc.
Amount evolved from manured pots	577	1,134	952	983
,, ,, ,, unmanured pots	391	702	634	788
Increased evolution due to manure in per cent.	47%	61%	50%	24%

Thus the evolution of Oxygen was increased on the average by 48 per cent. in the presence of green-manure and that this extra gas was utilized by the crop is shown in the following table :—

TABLE X.

Showing amount of Oxygen in cc. absorbed by manured and unmanured crops from February 24th, 1913, *to April 23rd,* 1913.

	Series I.		Series II.	
	Manured.	Un-manured	Manured.	Un-manured.
Oxygen evolved from cropped pots—cc.	93·8	37·7	31·6	22·7
,, ,, ,, uncropped pots—cc.	276·0	180·2	523·3	391·1
Difference indicating the amount absorbed by crop	182·2	142·5	491·7	368·4

In both series there is more Oxygen absorbed by the manured crop than by the unmanured crop to an extent, on the average, of 31 per cent. Consequently, not only does the addition of green-manure to a soil lead to an increased evolution of Oxygen, but this increased amount is available and is utilized by the crop. Thus, apart from all considerations of manurial value or its function in altering the physical texture of the soil *one of the most important*

functions of green-manuring lies in promoting an increased activity of the surface film which leads to greater aeration of the roots.

The practice of green-manuring, so general in South India, is, therefore, quite sound in principle so long as there is drainage present in the soil. It is only when the drainage is deficient that the toxins produced during the fermentations are able to affect the growth of the crop detrimentally, and under these conditions, the green-manuring should only be undertaken after careful consideration and even then with great circumspection.

Summary to Part II.

These investigations have led the authors to the conclusion that the surface film of algæ, etc., which covers the surface of swamp paddy soils and which evolves large quantities of Oxygen, is the chief agent in causing the aeration of the roots of the crop.

The Oxygen evolved by this film is dissolved in the irrigation water and thus produces a very highly aerated solution from which the roots derive the Oxygen essential for them. In undrained soils, this solution does not penetrate into the soil, and, consequently, the roots are congested near the surface of the soil and the amount of soil from which they derive their food is therefore limited and the crop suffers. In drained soils this strongly aerated water penetrates the soil and the roots are able to penetrate to a greater depth. The mass of soil from which the food supply is drawn is increased and the crop benefits in proportion.

Too great a rate of drainage decreases the formation of the film and the aeration of the roots is thereby lessened. There is therefore for all swamp paddy soils an optimum rate of drainage which produces the greatest aeration and this rate of drainage is a comparatively slow one.

Aeration of these soils by atmospheric Oxygen is not as effective in promoting root aeration as is aeration by the water draining through them.

The use of green-manures in drained paddy soils induces a greater activity on the part of the surface film, thus leading to a better aeration of the roots.

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PREFACE.

THE investigations which form the basis of this Memoir have been in progress since the year 1909, and although they cannot be said to have reached finality yet the character of the results obtained, and their connection with the growth of the crop makes it desirable to put them on record. It is hoped that they will attract attention to the peculiar conditions of these swamp soils and accentuate the difference between them and dry soils.

We wish it to be clearly understood that our experiments have been conducted with, and our conclusions apply only to, such paddy soils as are in a swampy condition from before the time of transplanting the crop into them up to about the time of harvest, and we make no claim that they apply to paddy soils other than to the type under consideration. Our own experiments make it only too clear that the conditions obtaining in upland paddy soils, in soils which are under dry conditions during part of the growing season, and in many soils depending on the rainfall for their moisture, are of a totally different order, at least during a portion of the period.

In order to permit of a better consideration of the subject it has been found desirable to divide this Memoir into two portions. Part I deals solely with the gases present in the soil and Part II deals with the gases evolved from the surface of the soil and their relationship to the aeration of the roots.

We would here take the opportunity of thanking our colleagues connected with the Madras Agricultural Department for the helpful criticism advanced by them during the progress of the investigation, and for the readiness with which they have put the fruits of their experience and special knowledge at our disposal. We would also thank Dr. E. J. Butler for bringing to our notice the work of Brizi in Italy on the aeration of paddy roots, work which has enabled us to deal with greater confidence with a difficult subject.

W. H. H.
P. A. S.

December 1924 CHEMICAL SERIES VOL. VII, No. 6

MEMOIRS OF THE DEPARTMENT OF AGRICULTURE IN INDIA

STUDIES IN THE CHEMISTRY OF SUGARCANE, II

SOME FACTORS THAT DETERMINE THE RIPENESS OF SUGARCANE

BY

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AND

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

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STUDIES IN THE CHEMISTRY OF SUGARCANE, II.*

SOME FACTORS THAT DETERMINE THE RIPENESS OF SUGARCANE.

BY

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Offg. Government Agricultural Chemist, Coimbatore;

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Assistant to the Government Agricultural Chemist, Coimbatore.

[Received for publication on 20th May, 1924.]

In a previous paper[1] submitted to the Bombay session of the Science Congress (1919) by one of us, the determination of the ripeness of sugarcane was one of the questions sought to be investigated. The paper dealt with the preliminaries of the problem, and the experiments recorded therein aimed at finding out the inter-relations of one internode to another of the same cane with the ultimate object of basing some method of determining the ripeness of a cane on such relations. It has been shown that when the cane is young and consequently immature, the difference in the contents of total solids calculated as sucrose between a bottom internode and a top internode is very great and in favour of the one below, and as the cane becomes older and more mature this difference tends to disappear and even gets reversed in favour of the internode at the top.

The work carried out subsequent to the year 1919 with a number of varieties of canes and in different seasons, besides confirming the observations

* Paper read at the Indian Science Congress, Bangalore, 1924.

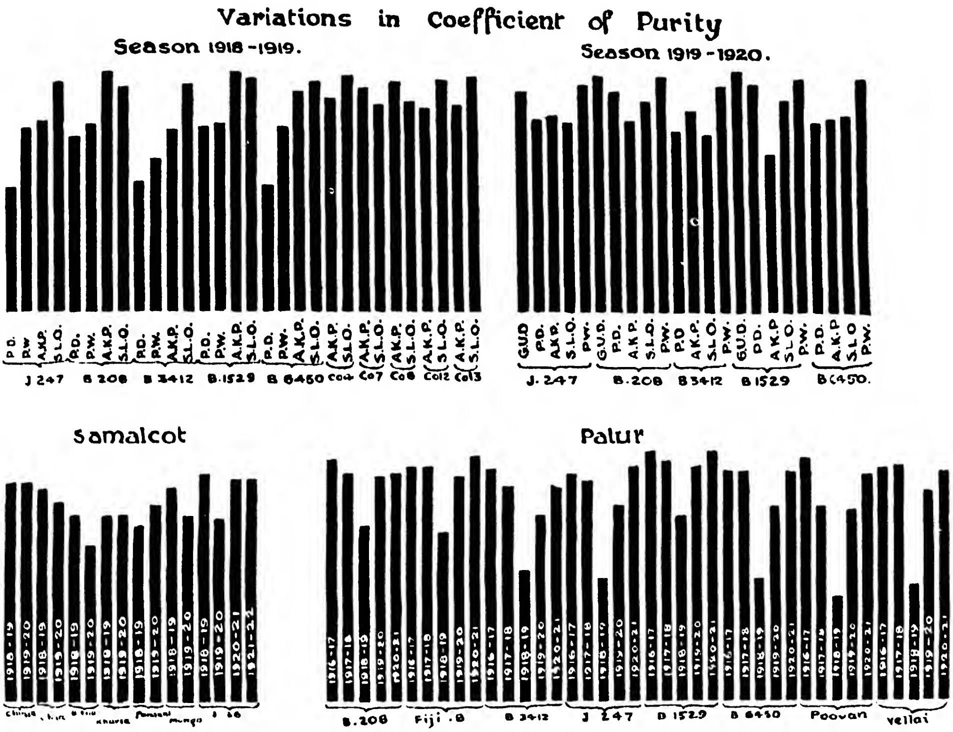
[1] *Agri. Jour. India*, XIV, 3.

previously recorded, brings prominently to our view certain factors which have a bearing on the determination of ripeness of sugarcane by chemical methods. The present paper is a record of these experiments and observations, and attempts at the improvement of the existing methods of chemical analysis of sugarcane.

Before presenting the subject proper it is essential to examine critically the methods that now obtain for determining the ripeness of a cane. The usual method is to determine the coefficient of purity of the juice of the cane under question, and when this coefficient reaches a certain value which is different for different varieties, the cane is declared to be ripe. In the case, however, of manurial experiments or varietal tests with new canes or seedlings a more detailed information is sought for by carrying out periodical analysis. Whether the test is one involving a single or many periodical analyses, the coefficient of purity has been the main guiding factor in judging when a cane is ripe, that is, fit for harvest either for *jaggery* (raw, crude sugar) or for sugar-making. The coefficient of purity differs with varieties. This is certainly a serious disadvantage, for the method becomes practically useless when the analyst is not acquainted with the variety. Still again for the same variety the coefficient is different in different places and soils. In other words, conditions of soil, climate, manuring, and irrigation affect the value of the coefficient to a very appreciable extent. In Tables I–IV will be found recorded the variations in the values of the coefficients found in different places for the same season and variety and for the same variety and place in different seasons. These figures are also shown graphically in Chart I. These coefficients were obtained from the results of analyses of canes analysed at a time when, in the opinion of the agricultural officers in charge of the experiment stations, they were considered ripe and fit for harvest. It will be found from the tables that differences of 5 to 10 per cent. in the coefficients between one place and another are quite common. Greater differences also occur though not so commonly. Palur figures for wet and dry lands for 1919-1920 are significant. Here the influence of soil conditions alone is exemplified. Similar differences are also noticeable for coefficients for various seasons in the same place. In Table IV(*a*) are recorded the variations in purity alongside variations in the total solid content. It will be found that differences much smaller than 5 per cent. correspond to a considerable increase in the total solid content and are therefore of no small importance in judging if a cane is ripe or not. This, taken in conjunction with the large variations detailed in Tables I–IV, clearly shows that the purity is not always a reliable factor for judging the maturity of a cane; especially when dealing with a cane the

nature or history of which one has no knowledge. For instance, if a cane like B ·208 which is reputed to give a juice of about 95 per cent. purity at the usual ripening season gives only a purity of about 80 to 85 per cent., it would

CHART I.



KEY.

P. D. = Palur dry land.
P. W. = Palur wet land.
A. K. P. = Anakapalle.
S. L. O. = Samalcot.
G. U. D. = Gudiyattam

be difficult to say whether the crop is ripe or not. The crop may not have come to the ripening state although it is about 11 or 12 months old, or the capacity of the crop is only that much ; which of them is the correct estimate we are not able to say from the data before us.

Migake Ishida[1] of the sugar experiment station, Formosa, has put forward another method of determining the ripeness of sugarcane. The following is the

[1] *Bull. Govt. Sugar. Expt. St., Formosa, Japan,* No. 1, pp. 6–7.

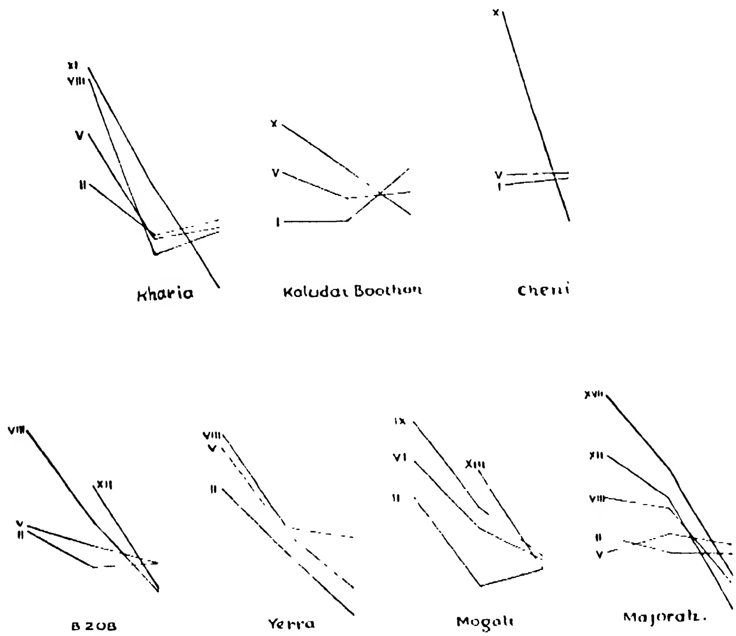
method as described by the writer himself. He says, "In the study of the maturity of the sugarcane the writer has proposed a new criterion which has been called the maturity coefficient. It consists in finding the ratio of reducing sugar to sucrose . . . . In experiments which have been pursued for several years upon many varieties of sugarcane it has been ascertained the period in which any variety of sugarcane makes a great change of its maturity coefficient, this period occurs at almost the same season every year and shows about the same value of coefficient, if the sugarcane, of course, is planted in the same season and other treatments are the same."

The results obtained by this author with a variety of cane known as Rose Bamboo are extracted in Table V for reference. Fuller details are not available, but from these two sets of figures, no doubt put forward by him as typical ones, it will be found that the new ratio is quite as unreliable as the old one. Like the coefficient of purity, the maturity coefficient also varies considerably. For instance, for the same variety of cane the maturity coefficient varied between 256·79 and 79·9 between the years 1912-13 and 1913-14. Again in the figures for 1913-14 there are two periods marked by the large increase in maturity coefficient referred to. During the fortnight between 26th December and 9th January the coefficient rises from 15·4 to 71·8; but during the two fortnights that follow 9th January it falls again almost to the original figure of 26th December to rise again on 6th March to 79·9. Besides the ratio is admittedly dependent for its value and period on temperature, soil conditions and methods of treatment. In the absence of additional information we cannot say anything definite about the method but, so far as available evidence goes, the method has nothing to recommend it in preference to the older one.

It is thus seen that the coefficient of purity or maturity are variable factors and therefore not always reliable for determining whether a cane is mature. It is natural that it should be so depending as it does on the sucrose content on the one hand and the other soluble substances of cane-juice on the other. In its place we have to search for a factor which can be more independent of the internal changes and adjustments of the cane. It is this consideration that prompted us to place more faith on the total solid content of the juice than on its sucrose or glucose contents, or any inter-relations between them. In the paper referred to in the beginning, it has been shown that, as the cane grows, there is a general levelling about the middle of the curves indicating either the possibility of the sugar moving upwards or its being used up in the formation of cane tissue. This fact presented in a slightly different light leads on to the conclusion we have arrived at, regarding the maturity of

a cane. In Table VI are given the results of examination of a few select internodes of a cane side by side with the increase of sugars in each internode between any two intervals. These increases are plotted against intervals for each cane in Chart II. It should be noted that these are the results of periodical examination of single canes while standing in the field according to the method detailed in the paper by one of us already referred to. It will be found that, during the early stages, the curves for the top internodes

CHART II.



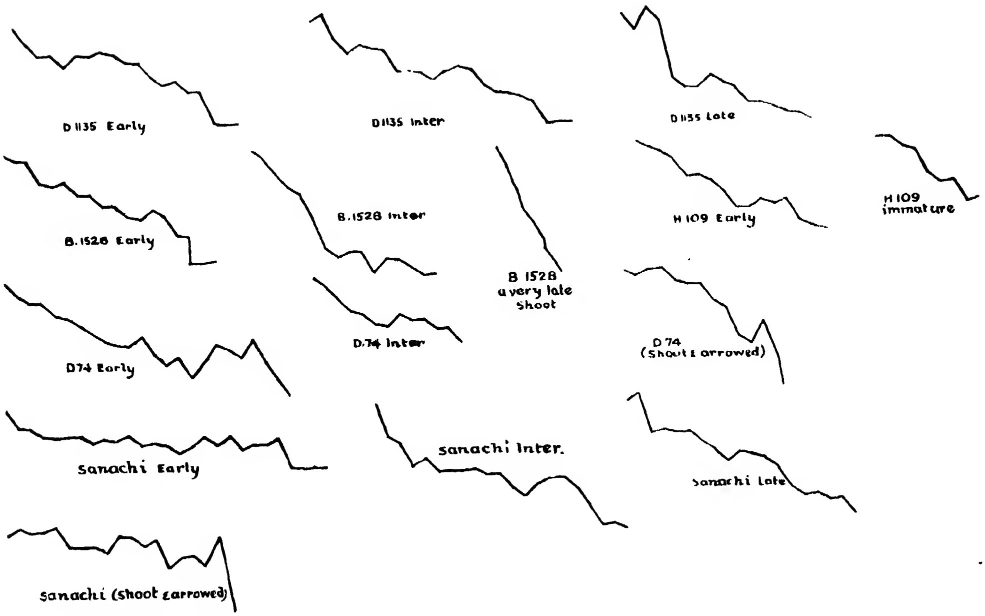
Showing rate of increase of total solids in each internode during intervals of a month.
Roman figures indicate the number of the internode from the bottom.
Ordinates = per cent. increase in total solids.
Abscissae = intervals.

stand always above those of the bottom ones. In other words, as the cane matures, whatever might be the fate of the sugars, whether they move upwards to fill up younger internodes or are used up in the building up of cane tissue, the general tendency is to equalize all differences in total-solid-contents between the various internodes up to the highest dead leaf joint. Conversely, when the total-solid-contents of the bottom and top internodes are equal or

nearly equal, i.e., when their ratio is unity or nearly unity, the cane may be declared to be ripe.

With the object of further confirming our hypothesis, about the latter half of April 1921, a dozen canes were marked out with botanical descriptions. Some of them were labelled as early or mature, some as intermediate, or maturing, while others were described as late or decidedly immature canes as judged by the eye. Each of these was examined, internode after internode,

CHART III.



Showing the shape of curves of canes of different age as judged by botanists.

for their total-solid-content by the refractometer. It was afterwards crushed and the coefficient of purity of the juice was determined. The results obtained by the refractometric analysis of these canes are put down in Table VII and plotted in Chart III. All the canes decidedly indicate, by the nature of the curves, immaturity to a greater or less extent. It will be seen from Table VIII that generally the ratio rises as the cane matures. But in no case is the ratio near unity. The reason for this is that owing to the late day in the season when the work was taken up, the canes had to be selected from a field which was

under harvest. In almost all the cases, the canes had to be cut from clumps carrying not more than 4 canes which were left as probably too young for crushing. It was, therefore, possible that all the canes were yet immature and constituted in each case a series of late shoots differing in age and maturity among themselves. It will also be seen that the coefficient of purity of the canes also generally varies as the top/bottom ratio, but no definite relationship seems to exist.

A comparison of the coefficients of purity obtained by us for each cane on the one hand with those cut for harvest from the same field in the same season amply supports the contention that the canes were all immature. In the same table are given both the sets of figures for the coefficients. It will be found that the coefficient of purity of the canes examined by us is always less than the corresponding bulk-harvest coefficients. There is therefore little reason to doubt their immaturity.

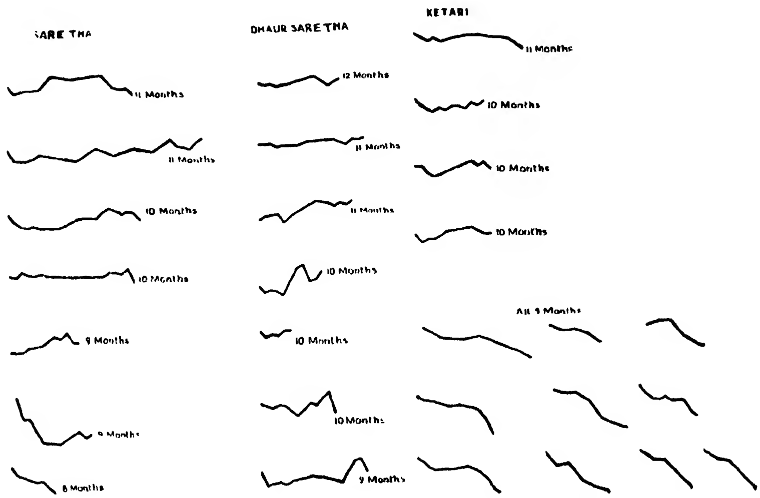
With a view to eliminate errors arising out of judging by the eye the stage of ripeness of the canes, experiments were arranged on an elaborate scale by the kind courtesy of the Government Sugarcane Expert. Four plots were reserved for this work exclusively at the cane-breeding Station and placed under our control and observation from the beginning of the season. As the shoots appeared they were labelled month after month as 1st, 2nd, 3rd and 4th shoots respectively according to their age. It was thought sufficient if each cane was marked as soon as cane formation set in above the ground level. The first shoots were labelled in July 1921, the second a month later in August, the third in September or October and the fourth in November.

Generally, according to our observations, the shooting is very liberal in the first month and this gradually decreases with the advance of time. Analysis of the canes thus marked was begun about the last week of December and were carried out at intervals of a month. The results presented in Table IX and Chart IV fully bear out the conclusions arrived at in 1919. As the canes become older and therefore more ripe, the curves also tend to become flatter and flatter.

In Table X will be found worked out the top/bottom ratios for the various canes against their age. In all these cases the age of the cane is definitely known and therefore the relative stages of maturity can be easily fixed. It will be found that there is a close relationship between the ratios and the stages of maturity. The former are characterized by their nearness to unity when the cane is mature with corresponding decreases at the younger stages. But what is more important than this confirmation of our results of the former

paper (1919) is the incidental proof that the ratio is independent of climatic and other conditions.

CHART IV.



Showing shapes of curves of labelled canes of different age.

It appears as though the effect of differences in climatic and soil conditions, while being widely different in the case of different canes, seems to be almost the same on the various parts of one and the same normal healthy cane, so far as the total-solid-contents are concerned. The work carried out in four different seasons shows a remarkable consistency in the general nature of the curves, considering the fact that we are dealing here with a living organism.

It is thus seen that from the nature of the curve formed by plotting the refractive indices of the juice of the internodes of any cane it is possible to judge of the stage of ripeness of that particular cane. As an alternativ rough and ready method the ratio of the total-solid-contents of the juices o. the bottom internodes and that of the internode carrying the highest dead leaf joint may also be used as a criterion in determining the ripeness of a cane. The latter method, however, cannot always be expected to give reliable results for the reason that the joint carrying the highest dead leaf attains to its maximum total-solid-content only some time after its leaf is cast or ceases to function. That this is the case has been shown in the 1919 paper already referred to. In a certain set of physiological experiments conducted for a different purpose we have noticed that it generally takes about three weeks

for a young internode to set its house in order and attain its optimum total-solid-content. If, therefore, the fixing of top by bottom ratio occurs before the internode is full, the ratio as determined from the highest dead leaf joint will naturally be low indicating immaturity, while in fact the cane is mature. The one striking feature of the curves of ripe canes is their relative flatness as distinguished from the definitely steep curves of the younger ones. This emboldened us to presume that generally if a cane is divided into two halves and crushed, the juices thus obtained contain practically the same amount of total solids in the case of a ripe cane. To put it in the language of the ratios, the ratio of the brix of the top juice to that of the bottom juice will be nearly unity; and in the case of an unripe cane the ratio will be much less than unity. This method of arriving at "ratios" minimizes to a very great extent the uncertainties attendant on the fixing of ratios with single top and bottom internodes.

The next step in the course of the investigation is to see if this method could possibly be applied on the field scale. In Table XI are to be found the ratios thus obtained for four seasons at Palur. In all cases the analyses were conducted at a time when the agricultural officers in charge of the experiment station judged the crop to be ripe for harvest. Except in two cases the ratios are all on that side of 0·9 nearer to unity. It should be noted that these values were obtained not for canes cut up to the highest dead leaf joint, but for those cut in the way in which an ordinary ryot does for *jaggery* making i.e., a few internodes above the highest dead leaf joint.

Experiments were started during the last season this time also at the Sugarcane Breeding Station and by the kind permission of the Government Sugarcane Expert. The general scheme was to label sufficient number of canes early after planting and to analyse some of them periodically for the top and the bottom juices. This would enable us to compare the age of the cane with the ratios of top and bottom juices of canes of varying age. A few rows of Ketari, Saretha, B. Cheribon and Manjav were labelled for the first, second, third, and fourth shoots, etc. An interval of about a month and sometimes more was allowed between any two labellings. This would give us canes of varying age. Analysis was begun during the latter half of August and continued at intervals of a fortnight until the canes were dead ripe. The results are presented in Table XII. It will be found that as the cane advances in age, the ratio rises towards unity. But what is more to the point is that with such a rise in the ratio there is an increase in the percentage of total solids; Ketari for which it was possible to get a complete set of results, fully supports the assumption. It is a native of Bihar, a vigorous growing variety,

which neither ripens early nor late. The ratio of the top and bottom juices rises towards unity from period to period of analysis and from one order of the shoot to an older one. This rise is further attended with definite increase in brix and sucrose content. Manjav shows a similar behaviour although it belongs to the class of thick or exotic canes. Black Cheribon, another thick variety, is slightly abnormal in its behaviour ; it was not in healthy condition and did not come off well in our experimental plot at the cane-breeding station.

Further experiments are in progress to test the application of this method to larger areas. A few trials of bulk analysis conducted on the above lines at Samalkot and Anakapalle are very encouraging. These and such others will form the subject of a separate communication.

SUMMARY.

1. Work done during eight seasons show that, in general, as a cane ripens, the various internodes show a levelling tendency in the matter of their total-solid-contents.

2. The purity alone is not always a reliable criterion for judging the maturity of a cane crop.

3. In testing the stage of maturity of a cane, the ratio of top brix to bottom brix is quite handy and accurate.

We are indebted to Rao Sahib T. S. Venkatraman, Government Sugarcane Expert, and his assistants for the facilities afforded us in this investigation, particularly to Mr. Thomas who helped us a good deal in the preparation of labels, etc., and to Mr. Edmunds, Deputy Director of Agriculture, for allowing field scale tests on his crops at Samalkot and Anakapalle in 1922.

Note. Since submitting this paper for publication we have had access, about the middle of June 1924, to a new book by R. A. Quintus, entitled " The Cultivation of Sugarcane in Java," and through it the work of Dr. P. L. Lohr published in *Archief* 1920.

There is a close resemblance between the results obtained by Dr. Lohr and those obtained by us, and he comes to the same conclusion as ours in regard to the testing of the ripeness of sugarcane.

In discussing the determination of maturity of sugarcane, Quintus says : " Dr. P. L. Lohr proved that the tripartite analysis is sufficient and in some cases gives more reliable data than that of ten parts. The nearer the sugar percentages of the lower and upper parts approach each other the riper the cane is ; or rather, if these percentages approach each other the greatest possible quantity of available sugar is then present .... " [B. V. N. AND S. K.]

TABLE I.

Varying coefficients of purity in different soils and localities.

Name of variety		1918–19 Palur dry lands		Palur wet lands		Anaka-palle	Samal-kot	Limits between which the coefficient varies	1919–20 Gudiyatham		Palur dry lands		Anaka-palle	Samal-kot	Palur wet lands		Limits between which the coefficient varies
J 247 ..	Bot. ..	65·59	58·38	76·97		79·24	91·28	58·38—91·28	91·14	88·47	83·40	79·80	80·9	78·70	92·65	90·55	78·70—90·55
	Top ..	51·16							85·80		76·20				88·44		
B 208 ..	Bot. ..	78·93	74·18	79·99	77·81	93·68	88·80	74·18—93·68	97·03	93·74	92·37	88·61	80·0	85·50	94·40	94·40	80·00—94·40
	Top ..	69·42		75·62					90·45		84·85				94·41		
B 3412 ..	Bot. ..	63·26	60·28	66·50		76·35	90·11	60·28—90·11	..		83·21	77·14	83·1	75·60	91·20	90·78	75·60—90·78
	Top ..	57·29									71·06				90·35		
B 1529 ..	Bot. ..	78·42	77·44	78·43		93·56	91·78	77·44—93·56	96·45	96·17	91·88	91·72	70·1	87·40	94·86	94·22	70·10—96·17
	Top ..	76·46							95·86		91·56				93·57		
B 6450 ..	Bot. ..	68·92	58·47	77·15		87·63	90·63	58·47—90·63	..		84·24	79·95	81·2	81·50	93·67	94·34	79·95—94·34
	Top ..	48·02									75·66				95·00		
Co 4 ..	..	..		..		85·65	92·75	..	..		..		..	..	..		..
Co 7 ..	..	..		..		89·00	84·09	..	..		..		..	..	..		..
Co 8 ..	..	..		..		91·54	84·91	..	..		..		..	..	..		..
Co 12 ..	..	..		..		82·99	92·33	..	..		..		..	..	..		..
Co 13 ..	..	..		..		84·19	93·17	..	..		..		..	..	..		..

TABLE II.

Varying coefficients of purity in the same locality (Samalkot) for different seasons.

Name of variety	1917–18	1918–19	1919–20	1920–21	1921–22	Limits between which the values vary
Chinia ..	98·3	86·67	68·70	..	..	68·70—98·30
Chin	88·5	84·55	81·00	..	..	81·00—88·50
Barouka ..	93·5	76·69	67·70	..	..	67·70—93·50
Kharia ..	92·5	76·90	76·80	..	..	76·80—92·50
Pansahi ..	91·4	74·20	80·00	..	..	74·20—91·40
Saretha ..	99·2	81·83	80·70	..	..	80·70—99·20
Mungo ..	82·6	85·30	76·80	..	..	76·80—85·30
B 3412 ..	..	90·10	75·63	87·8	88·30	75·63—87·80
J 36 ..	..	91·30	84·90	90·7	82·40	82·40—91·30
Java Hebbal ..	..	94·20	89·10	93·0	86·30	86·30—94·20
CO. 1 ..	..	88·40	86·10	82·8	87·00	82·80—88·40

Table III.

Varying coefficients of purity in the same locality for different seasons.

Name of variety	1916–17		1917 18		1918–19		1919–20		1920–21	Limits between which the values vary
B 208										
Bot. ..	95·1	95·1	93·04	90·21	78·93	74·18	92·37	88·61	90·2	74·18 –95·10
Top ..	95·1		87·38		69·42		84·85			
Fiji B										
Bot. ..	93·2	91·6	94·53	92·01	76·86	72·19	91·34	89·46	96·3	72·19--96·30
Top ..	90·0		89·49		67·51		87·59			
B 3412										
Bot. ..	91·8	90·5	89·51	85·72	63·26	60·28	83·21	77·14	85·90	60·28—90·50
Top ..	89·2		81·92		57·29		71·06			
J 247										
Bot. ..	90·3	90·5	89·15	88·48	65·59	58·38	83·40	79·80	91·7	58·38—91·70
Top ..	90·6		87·81		51·16		76·20			
B 1529										
Bot. ..	96·3	96·5	96·31	94·04	78·42	77·44	91·88	91·72	96·50	77·44—96·50
Top ..	96·7		91·77		76·46		91·56			
B 6450										
Bot. ..	91·3	90·9	92·88	91·44	68·92	58·47	84·24	79·95	90·5	58·47—91·44
Top ..	90·6		90·00		48·02		75·66			
Poovan										
Bot. ..	94·8	94·7	83·88	80·10	57·85	51·93	79·56	78·55	90·4	51·93—94·70
Top ..	94·6		76·32		46·00		77·54			
Vellai										
Bot. ..	91·0	91·8	94·12	92·74	62·06	55·74	87·22	85·34	90·5	55·74—92·74
Top ..	92·6		91·35		49·42		83·46			

Table IV.

Varying coefficients of purity in the same locality (Taliparamba) for different seasons.

Name of variety	1916–17	1917–18
B 6450	76·1	90·4
B 3412	82·4	90·0
Pansahi	79·9	88·4
Barouka	55·2	74·0
Saretha	85·0	81·8
Kari	78·7	84·8
Chinia	60·8	46·1

Table IV(*a*).

Variations of the purity coefficient with variations in the corresponding brix value.

Date of analysis	First shoots		Second shoots		Third shoots		Fifth shoots	
	Brix	Purity	Brix	Purity	Brix	Purity	Brix	Purity
21—VIII—1923 ..	17·57	84·86	17·07	85·24	16·27	82·42	15·16	79·68
10—IX—1923 ..	18·92	87·52	18·28	87·52	18·32	85·96	17·51	84·78
24—IX—1923 ..	19·05	88·14	18·70	88·78	18·44	88·08	18·19	86·76
12—X—1923 ..	19·40	89·40	19·35	89·00	19·25	88·50	18·14	89·40
Rise during interval	1·83	4·54	2·28	3·76	2·98	6·08	2·98	9·72
Rise of purity for 1 degree brix ..	..	2·50	..	1·65	..	2·00	..	3·20

Table V.

Showing the periodical rise in maturity coefficient (Extracted from the Formosa Agricultural Exp. Station Bull. No. 1).

Date	1912-13			1913-14		
	Sucrose	Reducing sugars	Maturity coefficient	Sucrose	Reducing sugars	Maturity coefficient
November 1 ..	5·44	1·303	4·20	10·70	1·587	6·7
,, 15 ..	9·35	1·071	8·70	9·50	1·623	5·9
,, 29 ..	8·12	0·832	9·80	10·77	1·072	10·0
December 26 ..	13·38	0·687	19·50	12·40	0·804	15·4
January 9 ..	13·58	0·198	70·10	13·49	0·188	71·8
February 20 ..	13·04	0·163	80·00	14·51	0·772	18·8
March 6 ..	13·10	0·051	256·79	13·91	0·174	79·9

Table VI.

Showing rise in total solids of the juices of a few internodes of canes during intervals of a month.

Name of cane	Number of internode from bottom	Analysed in Dec.	Rise during Dec.-Jan.	Analysed in Jan.	Rise during Jan.-Feb.	Analysed in Feb.	Rise during Feb.-Mar.	Analysed in Mar.
B 208 ..	2	22·12	0·89	23·31	0·14	23·17	0·04	23·13
	5	21·70	1·05	22·75	0·46	23·21	-0·04	23·17
	8	18·35	4·06	22·41	1·31	23·72	-0·92	22·82
	12	..	..	21·58	2·41	23·99	--0·78	23·21
Yerra ..	2	20·33	2·24	22·57	0·18	22·75	--1·73	21·02
	5	19·09	3·48	22·57	0·75	23·32	-0·92	22·42
	8	18·09	3·90	21·99	0·95	22·94	0·67	23·62
	10	..	..	21·39	0·74	22·13	0·23	22·36
Mogali ..	2	19·80	1·89	21·69	0·89	20·80	- 0·37	20·43
	6	18·12	3·00	21·12	0·89	21·99	0·06	21·93
	9	16·27	4·25	20·52	1·64	22·26	—0·02	22·24
	13	..	..	20·52	2·69	23·21	- 0·43	22·78
Majorah ..	2	17·97	0·58	18·55	0·07	18·62	0·01	18·63
	5	18·18	0·10	18·28	0·65	18·93	0·30	18·63
	8	15·84	1·84	17·71	1·52	19·23	· 0·89	18·34
	12	14·62	3·13	17·75	1·74	19·49	1·72	17·77
	17	12·12	4·98	17·10	2·74	19·84	--0·87	18·97
Kharia ..	2	17·02	1·59	18·61	0·02	18·63	0·45	19·08
	5	16·75	3·10	19·85	0·07	19·78	0·25	20·03
	8	16·13	1·92	21·05	0·62	20·43	0·12	20·31
	11	14·58	5·27	19·85	1·48	21·33	·1·58	19·75
Kaludai Boothan	1	19·28	0·43	19·71	0·42	20·13	1·96	22·09
	5	18·07	1·91	19·98	1·09	21·07	1·31	22·38
	10	16·50	3·42	19·92	1·97	21·89	0·59	24·47
Cheni ..	1	16·02	1·53	17·55	1·68	19·23	..	..
	5	15·42	1·78	17·20	1·88	19·08	..	..
	10	12·10	6·85	18·95	0·35	19·30	..	..

TABLE VII.

Total solid contents (calculated as sucrose) of various internodes of a cane as determined by the Refractometer during April 1921.

Number of the internode from the base	Name of variety with the probable stage of maturity														
	D 1135			H 109		B 1528			D 74			Sanachi			
	Early	Inter.	Late	Early	Late	Early	Late	Inter.	Late	Early	Shoot	Early	Inter.	Late	
1	22·73	23·74	22·47	23·35	22·12	23·32	24·50	24·30	20·68	23·72	22·80	20·17	21·23	19·24
2	22·67	24·14	21·45	23·35	22·05	23·02	23·10	23·70	20·13	22·86	22·57	19·12	19·18	19·59
3 . ..	21·82	22·74	22·85	23·07	21·45	22·87	20·72	22·80	19·33	22·51	22·87	18·92	18·73	17·24
4	21·02	21·73	21·95	22·82	21·20	21·51	18·67	21·87	18·63	22·41	23·02	18·52	17·33	17·18
5	21·02	22·18	18·45	22·32	19·75	21·26	15·82	21·42	18·28	21·56	22·27	18·42	17·68	17·18
6	20·27	21·98	17·85	21·23	19·20	21·46	16·17	19·97	17·73	21·41	22·02	18·42	17·03	17·18
7	21·01	21·85	17·85	21·19	19·25	20·66	14·07	18·07	17·53	21·46	21·92	18·37	16·93	16·58
8 . ..	21·01	20·55	18·60	20·94	18·05	20·66	..	17·52	18·28	20·21	20·94	18·07	17·03	16·08
9	21·16	20·55	18·18	20·24	18·20	19·98	..	17·82	17·93	19·81	20·49	18·17	17·03	15·43
10	21·01	20·35	17·78	19·32	..	19·98	..	17·89	18·03	19·81	18·74	18·17	16·78	15·93
11	20·59	20·02	16·87	19·32	..	19·33	..	16·39	17·38	19·56	18·19	18·42	16·68	15·82
12	20·44	20·52	16·87	19·67	..	19·08	..	17·34	17·38	20·21	19·74	17·92	15·93	15·52
13	19·59	20·92	16·57	19·47	..	19·68	..	17·34	16·38	19·01	17·39	17·92	15·48	14·86
14	18·99	20·62	16·27	19·67	..	19·33	..	..	..	18·11	12·79	17·82	16·02	13·66
15	19·39	19·67	16·17	18·42	..	18·13	..	15·79	..	18·81	..	17·27	16·53	13·21
16	18·58	19·17	15·67	17·97	..	17·88	..	..	..	17·46	..	17·77	16·53	13·21
17 . ..	8·58	19·12	..	17·82	..	16·28	..	..	..	18·41	..	18·42	15·78	12·91
18	16·83	18·88	..	..	..	16·28	..	..	..	19·61	..	17·87	14·78	12·91
19 .. .	16·17	18·48	..	..	..	16·38	..	..	..	19·21	..	18·42	13·53	11·86
20 .. .	16·71	17·23	..	..	..	..	..	..	..	18·71	..	17·47	13·53	..
21	..	17·23	..	..	..	..	..	..	..	19·91	..	17·82	13·12	..
22	..	17·23	..	..	..	..	..	..	..	18·36	..	17·82	..	..
23	..	..	..	..	..	..	..	..	..	17·16	..	18·22	..	..
24	..	..	..	..	..	..	..	..	..	16·11	..	16·32	..	..
25	..	..	..	..	..	..	..	..	..	..	..	16·17	..	..
26	..	..	..	..	..	..	..	..	..	..	..	16·17	..	..
27	..	..	..	..	..	..	..	..	..	..	..	16·17	..	..

TABLE VIII.

$\frac{Top}{Bot.}$ ratios of canes analysed in 1921 with their purities and the purities obtained by bulk-crushing of the same variety in the same season, place and plot.

Name of variety	Early		Inter.		Late		Coefficient of purity * (standard)
	Top/Bottom	Coefficient of purity	Top/Bottom	Coefficient of purity	Top/Bottom	Coefficient of purity	
B 3412 ..	0·85	85·71	..	..	..	..	84·0
D 1135 ..	0·74	85·45	0·73	85·49	0·70	80·10	91·0
H 109 ..	0·76	82·90	..	..	0·82	80·90	88·7
B 1528 ..	0·70	86·96	0·65	83·99	0·57	69·10	90·0
Sanachi ..	0·80	83·73	0·62	74·33	{ 0·60 { 0·54	70·60	..
D 74 ...	0·68	..	.	..	{ 0·60 { 0·56	81·51 79·97	85·7

* The figures under this column are the purities of the juices of corresponding varieties cut from the same field in the same year for harvest.

TABLE IX.

Showing total solid contents (calculated as sucrose), as determined by the Refractometer, of the various internodes of canes labelled and analysed during 1921–1922.

Saretha.

No. of internode from the base	Order of shoot	First		Second			Third	Fourth	
	Labelled on—	July 1921		August 1921			October 1921	November 1921	
	Analysed on -	16-XII-1921	26-I-1922	25-XII-1921	27-I-1922	28-II-1922	6-III-1922	28-II-1922	6-III-1922
1 ..	..	15·08	18·45	13·49	18·45	15·47	..	10·41	17·63
2 ..	..	14·78	17·10	13·49	17·60	14·57	20·36	9·26	17·03
3 ..	..	15·53	17·05	13·49	17·10	14·72	18·06	8·91	16·38 } Borer attack.
4 ..	..	15·23	17·05	14·01	16·90	14·87	18·06	8·64	16·38 }
5 ..	..	15·13	17·40	..	17·10	..	..	8·29	17·03
6 ..	..	15·23	17·85	14·44	16·90	14·91	15·32	8·29	..
7 ..	..	15·13	..	..	..	..	15·10	7·64	..

TABLE IX—*contd.*

Saretha—*contd.*

No. of internode from the base	Order of shoot / Labelled on / Analysed on	First		Second			Third	Fourth	
		JULY 1921		AUGUST 1921			OCTOBER 1921	NOVEMBER 1921	
		16-XII-1921	26-I-1922	25-XII-1921	27-I-1922	28-II-1922	6-III-1922	28-II-1922	6-III-1922
8 ..	..	..	..	15·39	..	16·79	..	6·94	..
9 ..	..	..	17·50	15·19	16·75	..	15·10	..	..
10 ..	..	..	..	15·79	..	..	..	..	..
11 ..	..	14·78	..	14·69	..	16·44	16·23	..	..
12 ..	..	..	17·10	14·59	17·85	..	16·48	..	..
13 ..	..	14·88	..	..	..	..	15·88	..	..
14 ..	..	..	..	..	..	16·74	16·23	.	..
15 ..	..	..	18·60	..	17·85	..	..		..
16 ..	..	14·88	..	..	18·45	16·79	..	..	..
17 ..	..	15·40	..	..	19·10	..	..		..
18 ..	..	15·30	17·70	..	16·30	15·21	..	..	..
19 ..	..	15·20	..	..	18·45	15·01	..	..	..
20 ..	..	15·70	..	.	18·60	15·11			..
21 ..	..	14·00	18·45	.	18·35	14·31	..	..	..
22 ..	..	..	..		17·50	..	..	.	..
23 ..	..	..	.		..	..	.	.	..
24 ..	..	..	18·10	.	..	..	..	.	..
25 ..	..	..	..	.	..	..	..	..	..
26 ..	..	..	..	..	..	..	..	..	..
27 ..	..	..	19·50	..	..	..	..	..	..
28 ..	..	..	18·60	.	..	..	..	..	..
29 ..	..	..	18·45	..	..	..	..	.	..
30 ..	..	..	18·30	..	..	..	..	..	..
31 ..	..	..	19·05	..	..	..	..	..	..
32 ..	..	..	19·50	..	..	..	..	..	..

TABLE IX.– *contd.*

Dhaur Saretha.

No. of internode from the base	Labelled on / Analysed on	First shoot, July 1921: 26-XII-1921	28-I-1922	1-II-1922	5-III-1922	Second shoot, August 1921: 25-XII-1921	28-I-1922	30-I-1922	5-III-1922
1 ..	..	20·46	21·38	21·70	22·34	16·19	22·50	16·10	21·72
2 ..	..	17·78	21·73	21·80	22·09	14·51	21·95	15·35	21·77
3 ..	..	20·01	..	21·80	22·09	14·84	22·10	15·50	21·52
4 ..	..	20·23	21·88	21·45	21·94	14·86	22·10	15·35	21·52
5 ..	..	20·23	21·08	21·45	..	14·71	22·50	14·90	20·32
6 ..	..	..	21·70	..	22·24	14·96	22·50	..	20·92
7 ..	..	19·03	.	21·45	..	..	..	18·45	22·42
8 ..	..	..	22·65	..	22·64	..	21·40	18·80	22·12
9 ..	..	20·53	..	21·95	..	15·53	..	16·65	..
10 ..	..	20·33	23·45	..	23·03	..	21·65	16·90	..
11 ..	..	..	..	22·05	..	15·33	..	17·85	..
12 ..	..	21·08	23·20	..	22·08	..	21·65	..	..
13 ..	..	21·83	22·95	22·05	22·38	.	..	..	.
14 ..	..	19·33	23·20	..	22·63	14·73	..	..	..
15 ..	.	..	23·10	21·45	..	16·18	..	..	..
16 ..	..	..	23·35	21·95	..	17·38	.	..	..
17 ..	..	..	..	22·05	..	17·58	.	..	..
18 ..	..	..	.	22·05	..	16·23	..	..	..

TABLE IX.—*concld.*

Ketari.

No. of internode from the base	Order of shoot— / Labelled on— / Analysed on—	First, August 1921, 26-XII-1921	First, August 1921, 24-I-1922	First, August 1921, 1-II-1922	First, August 1921, 23-II-1922	Second, September 1921, 1-II-1922	Second, September 1921, 23-II-1922	Third, October 1921, 27-II-1922	Fourth, November 1921, 16-III-1922	Fourth, November 1921, 16-III-1922	Fourth, November 1921, 20-III-1922	Fourth, November 1921, 20-III-1922	Fourth, November 1921, 20-III-1922	Fourth, November 1921, 22-III-1922	Fourth, November 1921, 23-III-1922
1 ..	..	19·53	18·95	17·40	18·08	18·85	16·59	18·19	..	..	15·96	16·64	..	..	16·93
2 ..	..	18·98	18·20	17·25	17·48	17·90	15·94	17·59	15·46	18·56	..	..	15·81	14·58	..
3 ..	..	18·28	18·35	16·70	17·12	17·25	15·34	17·39	..	..	14·21	15·09	..	..	15·88
4 ..	..	18·03	18·45	16·05	17·37	17·15	15·14	17·24	14·86	..	..	..	15·16	13·93	..
5 ..	..	18·03	..	..	16·97	17·50	15·44	..	..	17·31	14·51	14·94	..	..	15·58
6 ..	..	..	19·25	16·70	..	17·00	15·44	16·94	14·86	..	..	..	15·16	13·86	..
7 ..	..	17·98	..	..	17·27	17·00	15·74	..	..	..	12·41	15·39	..	..	13·86
8 ..	..	..	19·45	17·30	..	17·00	15·83	16·89	13·86	17·01	..	..	14·21	13·31	..
9 ..	..	18·23	..	..	17·57	15·45	15·48	..	..	..	11·61	14·44	..	..	12·21
10 ..	..	..	19·60	17·90	..	14·85	16·23	16·39	12·66	..	..	13·59	11·91	12·21	..
11 ..	..	17·58	19·25	17·40	17·57	..	15·83	15·99	12·51	17·46	10·91	..	..	11·96	..
12 ..	..	16·83	18·85	17·65	..	..	16·23	15·04	..	..	..	..	11·26	..	..
13 ..	..	15·66	18·85	17·00	17·39	..	..	13·34	..	..	..	..	..	..	..
14 ..	..	15·06	..	..	..	..	..	..	..	16·51	..	..	10·61	..	..
15 ..	..	..	..	..	17·24	..	..	..	..	..	..	..	..	..	..
16 ..	..	..	..	..	17·14	..	..	..	..	..	..	..	..	..	..
17 ..	..	..	..	..	..	..	..	..	..	15·46	..	..	..	..	..
18 ..	..	..	..	..	15·99	..	..	..	..	..	..	..	..	..	..
19 ..	..	..	..	..	..	..	..	..	..	14·66	..	..	..	..	..

TABLE X.

Ratio of $\frac{\textit{Total solids of the top internode}}{\textit{Total solids of the bot. internode}}$ *of canes with their age.*

Name of variety	8 months old	9 months old	10 months old	11 months old	12 months old
Saretha	0·67	1·08	0·94	0·93	....
	....	....	0·94	1·06	....
Dhaur Saretha ..	....	1·00	0·95	1·02	1·01
	....	....	1·00	1·02	....
	....	....	1·11	1·09	....
Ketari	....	0·74	0·99	....	....
	....	0·79	0·98	....	....
	....	0·77	0·98	....	....
	....	0·68	....	....	....
	....	0·81	....	....	....
	....	0·82	....	....	....
	....	0·87	....	....	....

TABLE XI.

Ratio of $\frac{\textit{Brix of Juice of Top half}}{\textit{Brix of Juice of Bot. half}}$ *of canes examined.*

Name of variety	1916-17	1917-18	1919-20	1921-22
Fiji B	0·99	0·93	0·99	0·87
B 208	0·97	0·94	0·94	0·97
B 1529	0·97	0·89	0·93	0·92
B 147	0·97	....	0·90	0·86
Vellai	1·00	0·98	0·93	0·94
B 6450	0·95	0·91	0·98	0·92
B 3412	0·97	0·89	0·96	0·95
J 247	0·98	0·93	0·89	0·89
Green Sports	1·00	0·94	0·94	....
Poovan	0·95	1·09	1·03	....
Red Mauritius	0·95	0·94	0·94	....
Striped Mauritius	1·03	0·97	1·03	0·94
Ashy Mauritius	0·98	0·96	0·99	0·84
Fiji C	0·96	0·94	0·92	....

TABLE XII.

Showing rise of the ratio of $\frac{\text{Top half}}{\text{Bot. half}}$ towards unity with advancing age along with the brix, sucrose and purity of the juices analysed.

Name of variety	Analysed on—	Order of shoot	Brix	Sucrose	Purity	Brix Bot.	Brix Top	Ratio $\frac{\text{Top}}{\text{Bot.}}$
Ketari ..	21-VIII-1923	First	17·57	14·81	84·86	18·62	16·50	0·89
		Second	17·07	14·55	85·24	18·72	15·20	0·81
		Third	16·27	13·41	82·42	18·01	14·70	0·81
		Fifth	15·16	12·07	79·68	17·11	13·49	0·79
	10-IX-1923	First	18·92	16·56	87·52	19·52	18·40	0·95
		Second	18·28	15·91	87·52	19·22	17·41	0·91
		Third	18·32	15·75	85·96	18·62	17·74	0·93
		Fourth	..	..	..	..	..	..
		Fifth	17·51	14·84	84·98	18·77	16·27	0·87
	24-IX-1923	First	19·05	16·79	88·14	19·52	18·41	0·94
		Second	18·70	16·60	88·78	19·52	17·81	0·91
		Third	18·44	16·24	88·08	19·12	17·40	0·91
		Fourth	..	..	..	..	..	..
		Fifth	18·19	15·78	86·76	18·92	17·00	0·90
	12-X-1923	First	19·40	17·28	89·06	19·37	19·17	0·99
		Second	19·35	17·22	88·98	19·48	19·12	0·98
		Third	19·25	17·12	88·93	19·48	18·72	0·96
		Fourth	18·78	16·78	89·35	18·60	17·70	0·95
		Fifth	18·14	16·22	89·41	18·57	17·40	0·94
	3-XI-1923	First	19·32	17·33	88·00	19·32	19·42	1·01
		Second	18·32	16·36	89·30	18·22	18·22	1·00
Manjav ..	22-VIII-1923	First	18·45	16·45	89·16	19·52	17·30	0·89
		Second	15·74	13·29	84·43	18·32	13·39	0·72
		Fifth	14·12	11·09	78·54	17·10	11·08	0·65
	11-IX-1923	First	18·44	16·37	88·78	19·83	16·93	0·85
		Second	16·84	14·60	86·70	19·03	14·57	0·77
		Third	18·34	16·08	87·26	18·98	17·87	0·94
		Fifth	15·54	12·77	82·19	18·18	13·30	0·73
	24-IX-1923	First	18·67	16·87	90·36	19·31	18·11	0·94
		Third	18·30	16·41	89·67	19·31	17·20	0·89
B-Cheribon .	22-VIII-1923	First	17·34	15·19	87·80	19·12	15·50	0·81
		Second	17·04	14·87	87·41	19·62	14·10	0·72
		Third	15·34	13·24	86·30	15·60	15·00	0·96
		Fourth	17·54	15·69	89·60	19·07	15·90	0·83
		Fifth	16·84	14·79	87·80	18·41	15·20	0·83
	11-IX-1923	First	17·87	15·82	88·55	18·59	16·98	0·91
		Second	17·81	15·61	87·66	19·19	16·22	0·85
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Memoirs of the Department of Agriculture in India

The Quality and Yield of Tobacco as Influenced by Manurial and other Operations

BY

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First Assistant to the Imperial Agricultural Chemist

AGRICULTURAL RESEARCH INSTITUTE, PUSA

Calcutta: Government of India
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THE QUALITY AND YIELD OF TOBACCO AS INFLUENCED BY MANURIAL AND OTHER OPERATIONS.

BY

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(Received for publication on 8th April 1925.)

I. Introduction.

Ordinary tobacco (*Nicotiana Tabacum*) is extensively cultivated throughout India. The area [1] occupied by the crop is estimated at 1,101,000 acres, of which 120,300 acres are under cultivation in Bihar and Orissa alone. The value of the crop is over 150 million rupees which would bring tobacco into sixth position of importance among the crops in India.

India stands second among the tobacco-growing countries of the world as regards the quantity of the crop produced, the first in order of production being the United States of America. Though tobacco is one of the principal crops of India, the quality is somewhat inferior and the market price of the product is considerably lower than that of most of other countries.

Howard and Howard [2] have made a study of the tobacco crop in India and have suggested a number of improved methods of growing this crop (the raising of its seedlings, its planting, its cultivation, etc.) suitable to local conditions. The present publication, however, deals with the subject of Indian tobacco from a chemcial standpoint. The objects of the investigation are considered under the following three heads :—

(1) A study of the effect of a variety of manures and fertilizers on the yield, quality and nicotine content of tobacco plants.

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[1] *Agri. Stat. of India*, 1919-20, Vol. I.
[2] *Agri. Res. Inst. Pusa, Bull* 50.

(2) A comparative study of the effect of such operations as "topping" and "spiking" on the yield and quality of tobacco plants.

(3) A comparative study of the changes occurring during the process of curing by the ordinary country method and by the so-called "rack-curing" method.

At present most of the information which is available on these points is to be found in publications issued by the Agricultural Bureau in America or by Landw. Versuchs station. As, however, Indian climatic conditions and soils are so widely divergent from those found in the countries referred to, the results arrived at will require careful checking by experiments made in India before they can be employed with any confidence here. In Bihar, the most extensive cultivation as well as the best tobacco comes from Tajpur Sub-division in Pergannah Sareysa, and Pusa being situated in the same Sub-division (Tajpur), the conditions there are favourable for carrying out such an investigation.

II. The Effect of Manures and Fertilizers on the Yield, Quality and Nicotine Content of Tobacco.

With a view to ascertain the effect of various manures and fertilizers on the yield, quality and nicotine content of tobacco, pot culture experiments and field trials were started in October 1916.

I. The effect on the yield.

The pot culture experiments consisted of eight sets of jars in duplicate, each set receiving different manurial treatment. All the jars were filled with the same amount of Pusa soil and constant moisture content was maintained alike in all the jars throughout the experiments. One set of jars was retained as a control and received no manure and the other sets had either farmyard manure, farm-yard manure in combination with superphosphate, superphosphate in conjunction with nitrate of soda, superphosphate mixed with saltpetre or superphosphate in combination with nitrate of soda and muriate of potash. In addition, there were two sets which received heavy doses of phosphatic and nitrogenous manures respectively in addition to a complete mineral manure.

Field trials were carried out at the same time as follows:—

An area of land about 30 ft. by 100 ft. was thoroughly cleaned of weeds and ploughed four times at intervals of about three weeks before it was divided into plots and tobacco seedlings transplanted in them. The area was divided into fourteen plots each 12 ft. by 15 ft. arranged in two

parallel rows, each row having seven plots. Each plot was separated from its neighbours by fallowed strips of about 3 ft. across.

Plan of fertilizer experiment on tobacco, 1916-17.

Plots	Fertilizing materials per acre	Fertilizing elements per acre		
		Phosphorus	Potassium	Nitrogen
		lb.	lb.	lb.
A & A_1	None	*nil.*	*nil.*	*nil.*
B & B_1	Farmyard manure 5 tons	..	..	40
C & C_1	Superphosphate containing 12 per cent. soluble P_2O_5 5 cwt. ; saltpetre $2\frac{1}{2}$ cwt.	30	110	40
D & D_1	Superphosphate 5 cwt ; nitrate of soda 2 cwt.	30	..	40
E & E_1	Superphosphate 5 cwt. ; nitrate of soda 2 cwt. ; muriate of potash $1\frac{1}{2}$ cwt.	30	75	40
F & F_1	Indigo *seeth* $2\frac{1}{2}$ tons	Not estimated	Not estimated	40

All the fourteen plots were manured on the same day and tobacco seedling which were about 4 inches high were transplanted next day in the afternoon. In each plot three varieties were sown ; they were—" Pusa Type 28 " in three lines having 15 plants, " Dhamakul " in one line having 5 plants and " Surujmukhi " in two lines having 10 plants.

So far as the general appearance of the plants in jars was concerned, those which had received an excess of 25 per cent. P_2O_5 over complete mineral manure were decidedly the best : the second in order were those treated with superphosphate mixed with saltpetre and those treated with superphosphate in combination with nitrate of soda and muriate of potash ; the third in order were those treated with superphosphate mixed with nitrate of soda and those treated with farmyard manure in combination with nitrate of soda. Plants grown in jars which were kept unmanured were decidedly inferior to all.

Table I gives, in a tabular form, the total fresh weight and the total dry matter of tobacco plants grown in pots under different manurial treatments.

TABLE I.

Jar No.	Fresh weight of plants in grm.	Weight of leaves after being cured in grm.	Total dry matter in leaves and stems in grm.	Treatment of jars
1 & 2	1,350	230	242·4	No manure.
3 & 4	2,070	303	411·5	Superphosphate and nitrate of soda.
5 & 6	2,170	336	413·9	Superphosphate and saltpetre (pot. nitrate).
7 & 8	2,260	328	431·1	Superphosphate, nitrate of soda and muriate of potash (pot. chloride).
9 & 10	1,820	279	315·1	Farmyard manure.
11 & 12	1,825	264	332·2	Farmyard manure and superphosphate.
13 & 14	1,885	281	342	Farmyard manure and nitrate of soda.
15 & 16	2,695	351	459·3	Excess of 25 per cent superphosphate, superphosphate, nitrate of soda and muriate of potash.

An examination of this tabular statement shows that the "potassium" increased the yield to a certain extent and a heavy dose of phosphatic manure in addition to a complete mineral manure improved the yield to a great extent.

TABLE II.

Treatment of plots	Fresh wt. of tobacco crops in kilos per plot	Total dry matter in kilos	Fresh wt. of crop calculated as yield per acre in kilos
No manure	15·540	2·923	3,822
Farmyard manure	19·795	3·613	4,872
Superphosphate and saltpetre	21·484	3·875	5,285
Superphosphate and nitrate of soda	18·488	3·616	4,547
Superphosphate, nitrate of soda and muriate of potash	20·871	3·856	5,133
Superphosphate and farmyard manure	21·469	3·935	5,281
Indigo *seeth*	20·249	3·657	4,984

Table II gives in a tabular form the results of field trials carried out same yeai (1916-17) with different manures and fertilizers. A complete mineral manure consisting of superphosphate, nitrate of soda and muriate of potash increased the yield by 34 per cent., superphosphate with farmyard manure increased it by 36 per cent., indigo *seeth* by 30 per cent., and farmyard manure by 28 per cent. As in the case of pot experiments potassium always increased the yield to a certain extent and a complete mineral manure gave the best results, but considering the high cost of such a complete mineral manure as superphosphate, nitrate of soda and muriate of potash no worse results were obtained with indigo *seeth* or with farmyard manure which are so easily available in Bihar and which cost also less.

In the following year 1917 another set of field experiments were laid down. In 1916-17 the individual effect of the manurial ingredients, *e.g.*, P_2O_5, N. K, was not tested and consequently in 1917-18 the field experiments were designed to test this point. The plots were arranged similarly to those of the previous experiments, but this time the size of each plot was larger, being 14 ft. by 25 ft. each. In each plot two varieties of tobacco " Pusa Type 28 " and " Surujmukhi " were grown.

Plan of fertilizer experiments on tobacco, 1917-18.

Plot	Fertilizing materials with rate of application per acre	Fertilizing elements per acre		
		Phosphorus	Potassium	Nitrogen
		lb	lb.	lb.
A & A_1	Superphosphate containing 20 per cent. soluble P_2O_5—2 cwt.	20	..	..
B & B_1	Superphosphate containing 20 per cent soluble P_2O_5—3 cwt.	30	..	..
C & C_1	None	..	..	..
D & D_1	Farmyard manure amount equivalent on P_2O_5 to 2 cwt. superphosphate per acre.	20	..	30
E & E_1	Superphosphate containing 20 per cent soluble P_2O_5—2cwt., and saltpetre—2½ cwt.	20	110	40
F & F_1	Saltpetre 2½ cwt.	..	110	40

The results of 1917-18 field trials showed that the individual effect of superphosphate or saltpetre on the yield of tobacco was almost negligible, whereas these two in combination increased the yield by about 16 per cent. Farmyard manure used singly gave a still better result, the yield being increased by about

20 per cent. The use of a heavier dressing (3 cwt. per acre) of superphosphate singly in no way improved the yield. The results obtained are tabulated in Table III.

TABLE III.

Treatment of plots	Fresh weight of tobacco crop in kilos per plot	Total dry matter in kilos	Fresh weight of plants calculated as yield per acre in kilos
Superphosphate at 2 cwt. per acre	41·85	8·015	5,231
Superphosphate at 3 cwt. per acre	41·40	7·938	5,175
No manure	41·00	7·898	5,125
Farmyard manure	53·10	9·400	6,637
Superphosphate and saltpetre	47·25	8·766	5,962
Saltpetre	42·97	8·113	5,371

Combining the results of experiments carried on in jars in 1916-17 and the field trials carried on in two consecutive years 1916-17 and 1917-18 the figures obtained would seem to justify the following inferences.

(1) As the fertilizer for tobacco in Pusa soil. superphosphate or saltpetre used singly is not effective.

(2) A complete mineral manure such as superphosphate, sodium nitrate and muriate of potash gives an excellent effect.

(3) The presence of potassium in the fertilizer has regularly increased the yield.

(4) It appears that the greatest total yield is produced by a fertilizer containing relatively more phosphorus in proportion to nitrogen than is found in ordinary farmyard manure (*vide* pot experiment, 1916-17, jars 15 and 16, and the field trails superphosphate and farmyard manure, 1916-17).

(5) As the fertilizer for tobacco, farmyard manure or indigo *seeth* occupies a leading position on account of their cheapness, their availability in Bihar and their great effectiveness.

The reason of the great effectiveness of farmyard manure or indigo *seeth* is quite obvious. Tobacco is a crop which will not grow well unless the soil is not loosened very frequently and the use of such organic manure as farmyard manure or indigo *seeth* makes the soil more porous. Bihar soil is generally poor in organic matter and the application of this constituent is attended with a good crop of tobacco.

2. The effect on the quality.

The quality of a tobacco depends on various properties such as burning qualities, size, weight, delicate structure, elasticity, colour and fermentative properties, and these in turn depend upon some of the chemical constituents of the tobacco plant. Fisca and Imai [1] deduce the following conclusions from their researches on the quality of tobacco :—" A high per cent. of nicotine has not been shown to be an indication of the good quality of tobacco. .... The albuminoids in a tobacco afford no indication of quality unless the proportion of amides is simultaneously considered. The amido nitrogen represents, for the most part, harmless, or perhaps even beneficial nitrogenous compounds. Any way the conversion of albuminoids into amides is one of the most important results of the fermentation......... Only considerable differences in the amount of the various constituents of tobacco can give any conclusive indication of the quality of a tobacco. Very bad tobacco always contains much albuminoid matter, sulphuric acid, chlorine and large quantities of mineral acids, with small proportion of amido nitrogen and potash." The various properties of tobacco just mentioned are more or less affected by the variety of tobacco, the soil, time and manner of manuring, manner of setting, treatment of the plant in the field, climate and time of harvesting. The properties of tobacco may also be materially affected by the manner of curing, the condition of the weather during drying and the fermentation itself. The fact that so many factors play a part in determining the quality of tobacco makes this subject an especially difficult one to study. In the experiments outlined above, other factors and condition of growth having been kept, as far as possible, the same, observations on the effect of different manurial treatments on the quality of tobacco were made.

Alexander Cserhati,[2] Harry Patterson,[3] Edward Jenkins,[4] Max Lehmann,[5] Rasmussen,[6] Adolf Mayer,[7] Nessler,[8] Johnson,[9] Fesca,[10] and Garner[11] carried out a series of experiments on the effect of different fertilizers and manures on the composition, quality and combustibility of tobacco. Since these experiments were carried out by different investigators at different places and under such varying conditions as soil, climate, etc., and since their conclusion are so varied, it seems, therefore, unreasonable to deduce any inference for one country from observations made in another of entirely different climate. The investigations of Adolf Mayer, Nessler, Fesca, Patterson and Garner seem to have shown beyond much doubt that potash

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1 *Jour. Soc. Chem. Industry.* vii, 759.
2 *J. Lander*, 1895, 43, 379-458.
3 *Marryland Stat. Bull.* 26, 57-92.
4 *Ann. Rep. Agri. Experi. Stat. Connecticut.* 1894 & 1896, 29, 322-333.
5 *Landw. Versuchs Stat.* 1903, 58, 439-470.
6 *Biochem Ztschr*, 69 (1915), No. 5-6, 461-466.
7 *Landw. Versuchs Stat.*, 38, 92-126.
8 ,, ,, ,, 90, 395-438.
9 *Connecticut Stat. Rep.* 1893, 112-127.
10 *Jour. Soc. Chem. Industry*, vii, 759.
11 *U. S. Dept. of Agri. Bureau of Plant Industry Bull.* 105.

is favourable to the glowing, that *chlorine* is unfavourable and that the effect of potash is most plainly seen when a part of the potash is in combination with organic acid, that is when the tobacco ash consists largely of bases with relatively low content of sulphates, chlorides and phosphates. Alexander Cserhati contradicts Nessler's statement that tobacco containing over 0·4 per cent. of chlorine with less than 2·5 per cent. of potash will not burn well, and declares that the view that cumbustibility of tobacco depends mainly on the amount of chlorine and potash it contains are erroneous. The opinions of these investigators with reference to the effect of fertilizers on organic constituents of tobacco, specially albuminoids, are much at variance.

In the present experiments the quality of the tobacco so far as physical texture of the leaf, colour, elasticity and size are concerned was determined by Mr. A. C. Acree, Director of the Indian Tobacco Development Company, Dalsing Sarai, to whom samples of tobacco grown under different manurial treatments were submitted. His report for the year 1916-17 runs as follows : " The quality of the samples is good enough for cigarettes and we could use the whole lot just as they are if the tobacco was taken off of the stalks and graded. S-E, *i.e.*, Surujmukhi grown by superphosphate, sodium nitrate and potassium chloride, and S-F, *i.e.*, Surujmukhi grown by superphosphate and farmyard manure, are the best of the lot from a texture point of view, but the colour is a little dark. S-F, *i.e.*, Surujmukhi grown by superphosphate and farmyard manure, is the better of the two. D-D, *i.e.*, Dhamakul grown by superphosphate and sodium nitrate, and D-G, *i.e.*, Dhamakul grown by indigo *seeth*, are fairly good, but on the papery side, D-G, *i.e.* Dhamakul, grown by indigo *seeth*, would be very good if it had more body. The seven samples P A to P-G, *i.e.*, seven samples of Pusa Type 28 grown by different manurial treatment, are just about the type we are buying here from the ryots. P-A, P-B, P-C and P-D, *i.e.*, Pusa Type 28 grown by either no manure or farmyard manure or superphosphate in conjunction with potassium nitrate or superphosphate with sodium nitrate, are all practically the same or so close I can tell no difference. P-E, *i.e.*, Pusa Type 28 grown by superphosphate, sodium nitrate and potassium chloride, and P-F, *i.e.*, Pusa Type 28, grown by superphosphate and the farmyard manure, while of the same type, are lacking in body and texture . P-G., *i.e.*, Pusa Type 28 grown by indigo *seeth*, is the commonest of the lot. P G, *i.e.*, Pusa Type 28 grown by indigo *seeth*, and D-D, *i.e.*, Dhamakul grown by superphosphate and sodium nitrate, are very alike in quality and texture, and these are the worst samples of the lot." It may be pointed out that, whereas S-E, *i.e.*, Surujmukhi grown by superphosphate, nitrate of soda and muriate of potash, and S-F, *i.e.*, Surujmukhi grown by superphosphate and farmyard manure, have been reported as the best of the lot from a texture point of view, P-E and P-F, two samples of Pusa Type 28 grown respectively by the same manures and in the same plot as S-E and S-F, have been reported as lacking in body and texture. Again the samples P-A, P-B, P-C and P-D which were grown with no manure, farmyard manure, superphosphate with saltpetre, and superphosphate with nitrate of soda, respectively, have all been reported as alike in quality.

Samples of tobacco which were grown in 1917-18 under different manurial treatment were reported by Mr. Acree as follows : " I have had a look at each of the samples separately and find that all of these samples will do for the manufacture of cigarettes :-

1. Surujmukhi grown by superphosphate at 2 cwt., superphosphate at 3 cwt., superphosphate with saltpetre	Good.
2. Surujmukhi grown by no manure, farmyard manure	Not so good.
3. Surujmukhi grown by saltpetre	Common.
4. Surujmukhi duplicate grown by superphosphate at 2 cwt., superphosphate at 3 cwt., per acre	Fairly good.
5. Surujmukhi duplicate grown by no manure, superphosphate with saltpetre, saltpetre	Good.
6. Surujmukhi duplicate grown by farmyard manure	Very good.
7. Pusa 28 grown by superphosphate at 2 cwt per acre	Very good.
8. Pusa 28 grown by superphosphate at 3 cwt., no manure, saltpetre	Good.
9. Pusa 28 grown by farmyard manure, superphosphate with saltpetre	Fairly good.
10 Pusa 28 duplicate grown by superphosphate at 2 cwt., superphosphate at 3 cwt., no manure, saltpetre	Good.
11. Pusa 28 duplicate grown by farmyard manure, superphosphate with saltpetre	Very good.

As in previous instances, so here too we find that Surujmukhi grown by superphosphate at 2 cwt. per acre and Surujmukhi grown by superphosphate at 3 cwt. per acre have been reported as "good," while their duplicate samples grown by the same manures under same condition have been reported as "fairly good." Again Pusa Type 28 grown by farmyard manure and Pusa Type 28 grown by superphosphate with saltpetre have been reported as "fairly good," while their duplicate samples grown by the same treatment and under same conditions have been reported as "very good." The facts prove beyond doubt that there is no definite relationship between the quality of tobacco (so far as texture, colour and body are concerned) and the different manurial treatments they receive. There does not appear to exist any constant relation even between the so-called quality of tobacco and the richness of the fertilizers used.

The samples of tobacco grown by different manurial treatments in the years 1916-17 and 1917-18 were analysed for their ash, potash, chlorine and protein contents *i.e.*, for constituents which have been generally recognized as affecting the quality of a tobacco. Table IV gives in a tabular form the analyses of the different samples of tobacco by different manurial treatments during 1916-17 and 1917-18. An examination of the figures in Table IV shows that the ash content has been hardly

affected by the different manurial treatments; the figures for ash content, in most cases, varied between short limits of 17 and 19·5 per cent. Similarly the protein contents or the ratios of amido nitrogen and albuminoid nitrogen to the total nitrogen have not been affected by the different treatment. For instance, superphosphate in case of Pusa Type 28 gave a comparatively high figure of 17·43 for amido nitrogen and a comparatively low figure of 43·9 for albuminoid nitrogen, while the same fertilizer gave in the case of "Surujmukhi" a comparatively low figure (in fact the lowest in the series) of 10·48 for amido nitrogen and a high figure (the highest in the series) of 60·76 for albuminoid nitrogen. Again a high figure for albuminoid nitrogen was obtained in one instance with superphosphate and saltpetre, while in another a lower figure was obtained with the same treatment. The potash in the tobacco, however, seems to be affected to some extent. Chemical fertilizers, in majority of cases, increased the potash content of tobacco, while organic manure as farmyard manure or indigo *seeth* with a very few exceptions gave a low potash content.

Table IV.

Treatment of plots	Pusa Type 28						Surujmukhi						Dhamakul		
	Pure ash %	Potash as K_2O %	Chlorine as Cl %	Total nitrogen %	Ratio of Amido nitrogen to total nitrogen	Ratio of Albuminoid nitrogen to total nitrogen	Pure ash %	Potash as K_2O %	Chlorine as Cl %	Total nitrogen %	Ratio of Amido nitrogen to total nitrogen	Ratio of Albuminoid nitrogen to total nitrogen	Pure ash %	Potash as K_2O %	Chlorine as Cl %
1. No manure	19·24	2·86	0·95	1·75	12·90	56·74	..	..	..	..	..	..	..	..	..
2. Farmyard manure	18·58	2·49	0·48	1·90	12·63	51·90	..	..	..	..	..	..	..	..	..
3. Superphosphate and saltpetre	18·75	2·80	0·34	2·05	13·66	53·27	..	..	..	..	..	..	17·46	3·14	0·16
4. Superphosphate and nitrate of soda	19·3	2·60	0·57	1·93	14·00	53·32	..	..	0·82	..	..	..	..	..	..
5. Superphosphate nitrate of soda and muriate of potash	19·41	2·74	1·07	1·90	13·68	54·74	17·99	2·69	0·18	..	..	..	..	..	...
6. Superphosphate and Farmyard manure.	18·85	2·24	0·39	2·15	14·42	47·72	19·27	2·90	..	..	..	..	..	..	..
7. Indigo *seeth*	20·51	2·24	0·77	1·78	12·36	57·42	..	..	..	..	..	..	16·58	2·21	0·61
8. Superphosphate at 2 cwt. per acre	48	4·00	0·60	1·55	17·43	43·90	17·25	2·93	0·21	2·03	10·48	60·76	..	..	..
9. Superphosphate at 3 cwt. per acre	18·69	3·63	0·15	1·61	17·48	41·55	18·17	2·86	0·16	1·85	14·87	55·13	..	..	..
10. No manure	18·77	3·46	0·15	1·78	17·75	42·02	16·45	2·67	0·17	2·00	14·70	50·80	..	..	..
11. Farmyard manure	17·20	2·20	0·24	2·10	15·57	51·00	17·62	3·31	0·69	1·68	16·00	50·35	..	..	..
12. Superphosphate and saltpetre		..		1·79	14·36	48·38	..	..	..	1·65	14·12	43·45	..	..	..
13. Saltpetre	..	..	..	1·96	13·72	51·89	..	..	..	1·81	15·03	52·49	..	..	..

Application of potassium chloride (muriate of potash) invariably increased the chlorine content which without doubt injures the burning capacities of tobacco. Addition of muriate of potash to superphosphate and nitrate of soda increased the chlorine content of tobacco by twice that which was obtained with superphosphate and nitrate of soda and by thrice that obtained with superphosphate and saltpetre. This fact was observed in the pot culture experiment of 1916-17, where tobacco from jars treated with superphosphate, nitrate of soda and muriate of potash gave the highest figure for chlorine.

In order to test the burning capacity or combustibility, tobacco samples which were grown by different manurial treatments in 1917-18 were sent to the Peninsular Tobacco Factory, Monghyr, where they were made into cigarettes of a particular length and diameter and as nearly as possible of the same compactness. The combustibility was tested by Toth's method[1] which enables one to numerically express the "combustibility" of a tobacco. The following figures were obtained, the value being the average of about six tests which were made with each samples.

Treatment of plot	Combustion value	
	Surujmukhi	Pusa Type 28
1. Superphosphate at 2 cwt., per acre	..	529
2. Superphosphate at 3 cwt per acre	710	..
3. No manure	527	525
4. Farmyard manure	558	516
5. Superphosphate and saltpetre	529	593
6. Saltpetre	467	445

There is little or no difference between samples grown by treatment 1, 3, 4 and 5 so far as combustibility is concerned. Saltpetre gave low value for both the varieties of tobacco tested, while a heavy dose of superphosphate (treatment 2) gave high combustion value. It was also observed that cigarettes made from tobacco which had been manured with saltpetre burnt quickly when smoked, whereas that receiving superphosphate burnt slowly and in some cases did not burn well when lighted. A combination of superphosphate with saltpetre produced a tobacco which burnt fairly well when smoked.

[1] *Rev. Internat. Falsi*, 1904, 17, 142-145.

Combining the results of two years experiments the following conclusions may be deducted : –

(1) The quality of tobacco so far as texture, colour, body, etc., are concerned bears neither any relation to the different manurial treatments it receives, nor to the richness of the fertilizers used.

(2) The ash, amido nitrogen and albuminoid nitrogen (constituents which have a bearing on the quality of tobacco) are hardly affected by different manurial treatments.

(3) Chemical fertilizers generally give a higher, and organic manure as farmyard manure or indigo *seeth*, a lower potash content (constituent which improves the burning quality of a tobacco).

(4) Application of muriate of potash (potassium chloride) as a fertilizer increases to a great extent chlorine content which injures the burning quality of a tobacco, other manurial treatments, having little or no effect on the chlorine content.

(5) Tobacco manured with saltpetre burns quickly when smoked, whereas that receiving superphosphate *burns* bad and slowly. A combination of these two manures produces tobacco which burns fairly well.

3. The effect on the nicotine content.

How far the nicotine content of a tobacco is affected by different manurial treatments and whether it bears any constant relation to the richness of the fertilizers used, has been the subject of investigation by a number of experimenters from time to time. Adolf Mayer[1] from a series of experiments on twelve one-fortieth acre plots, 11 being fertilized with various combinations of farmyard manure, nitrate of soda, caustic ammonia, superphosphate, Thomas slag, potash and double sulphate of potash and magnesia and one remaining unmanured, pointed out the influence of fertilizing materials on the quality of tobacco, and showed with reference to nicotine that its formation in the plant was favoured by a heavy application of easily available nitrogenous materials and that a high percentage of nicotine was in no case observed where the supply of plant food was deficient.

Jenkins[2] showed that the percentage of nicotine was above the average in tobacco to which large quantities of nitrogenous fertilizers had been applied. Passerine[3] found the percentage of nicotine in dry tobacco leaves from different plots as follows. –

Unfertilized plot 3·407 per cent., with 580 lb. dried blood per acre 2·533 per cent., with 267 lb. sulphate of ammonia 1·672 per cent., and with 356 lb. nitrate of soda 4·183 per cent. He thus concluded that there is no relation between the ni-

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[1] *Landw. Versuchs Stat.* 38. 92-126.
[2] *Connecticut State Stat. Rep.*, 1896, 310-333.
[3] *Staz-Sper Agri. Ital*, 28 (1895), No. 8. 513 529.

cotine contents of tobacco and the manurial treatment they receive. Garner[1] concluded that the percentage of organic nitrogenous compounds, including nicotine, is generally proportionate to the luxuriance and vigour of growth, and that conditions favourable to rank growth are brought about by the use of excessive quantities of nitrogenous fertilizers.

Rasmussen[2] from his studies with *Nicotiana rustica* and with Hungarian and Virginian varieties of tobacco showed that no clear and constant relation exist between the richness of the fertilizers used and the nicotine contents of tobacco plants.

In the present experiments, with a view to ascertain the effect of different manures and fertilizers on the nicotine content of tobacco, samples of tobacco grown in jars as well as in field during two years (1916-17 and 1917-18) were examined for their nicotine content. Table V gives the nicotine contents of tobacco grown in jars in 1916-17 with different manures and fertilizers and Table VI the nicotine content of tobacco grown in field during 1916-17 and 1917-18 with different manurial treatments.

TABLE V

No. of jars	Treatment of jars	Nicotine
1 and 2	No manure	5·12
3 and 4	Superphosphate and nitrate of soda	3·72
5 and 6	Superphosphate and saltpetre	5·02
7 and 8	Superphosphate, nitrate of soda and muriate of potash.	4·67
9 and 10	Farmyard manure	5·11
11 and 12	Farmyard manure and superphosphate	3·67
13 and 14	Farmyard manure and nitrate of soda	3·78
15 and 16	Excess superphosphate with nitrate of soda and muriate of potash.	4·27

An examination of the figures in Table V will show that although tobacco grown in unfertilized jars and in jars treated with farmyard manures were decidedly very poor in size and weight, they gave high nicotine contents, whereas those grown in jars receiving superphosphate and nitrate of soda or superphosphate, nitrate of soda and muriate of potash with much better growth and yield gave comparatively low nicotine contents.

In Table VI, a column giving the fresh weight of tobacco crop yielded against the column for the nicotine content has been added. If we now examine the figures

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[1] *U. S. Dept. of Agri. Bureau of Plant Industry, Bull.* 105.
[2] *Biochem. Ztschr.*, 69 (1915), 5-6, 461-466.

TABLE VI.

Year	Manurial treatment	Pusa Type 28			Surujmukhi		
		Nicotine per cent.	Fresh weight of crop in kilos	Kilos of leaves per kilo nicotine	Nicotine per cent.	Fresh weight of crop in kilos	Kilos of leaves per kilo nicotine
1916-17 .	No manure	3·17	7·48	31·5	..	..	..
	Farmyard manure . .	3·90	10·18	25·6	..	..	..
	Indigo *seeth* . . .	3·12	10·08	32·1	..	..	..
	Farmyard manure and superphosphate	4·15	9·79	41·5	..	..	..
	Superphosphate and saltpetre	3·93	10·63	25·4	..	..	..
	Superphosphate and nitrate of soda	3·65	8·32	27·4	..	..	..
	Superphosphate, nitrate of soda and muriate of potash	3·47	8·72	28·9	..	..	..
1917-18 .	No manure	4·05	38·70	24·6	3·99	43·25	25·1
	Farmyard manure . .	4·06	55·26	24·6	3·27	40·72	29·9
	Superphosphate at 2 cwts. per acre	3·47	42·52	28·9	3·46	41·17	28·8
	Superphosphate at 3 cwts. per acre	3·82	42·66	25·7	3·21	40·15	31·1
	Saltpetre	3·90	44·60	25·6	3·41	41·40	29·3
	Superphosphate and saltpetre	3·86	48·42	25·9	4·05	46·08	24·7

for the nicotine content along with the figures for the yield, we find that in case of Pusa Type 28 as well as in case of Surujmukhi the nicotine yield is, in majority of cases, proportional to the yield of the crop or in other words to the growth of tobacco. On the other hand, we also find that in case of Pusa Type 28 indigo *seeth*, though giving as high a yield as farmyard manure, gives a very low nicotine content (the lowest in the series) and no manure though giving a very low yield (the lowest in the series) gives as high a nicotine content as farmyard manure giving the highest yield in the series. Such irregularities have been observed in pot culture experiments too, where tobacco grown by no manure and farmyard manure, with a poor yield, gave a high nicotine content, and those grown by superphosphate and nitrate of soda or superphosphate with nitrate of soda and muriate of potash, with a much better yield, gave a comparatively low nicotine content. However, on the whole, the results clearly indicate that the nicotine content in tobacco is generally proportional to the yield or in other words to the growth of tobacco. Again when we examine the column containing kilos of leaves per kilo nicotine in Table VI we find that superphosphate or nitrate when applied alone tends to decrease the nicotine content, but a combination of these two manures tends to increase the proportion of nicotine.

Adolf Mayer[1] while studying the conditions of growth favourable to the development of nicotine content of tobacco, showed that not only manures but increased temperature, direct sunlight and increased humidity each individually favours the formation of nicotine, while an increased water content of soil, which is generally attended with a low dry matter of crop, hinders its formation. In general, it may be concluded that any factor which promotes the growth of the plant is advantageous to the formation of nicotine, and any which hinders the growth is disadvantageous to the formation of nicotine.

III. The effect of "Topping" and "Spiking" on the Yield and Quality of Tobacco.

"Topping" is an operation which consists in breaking the top at the growing point, when tobacco plants are 2 ft. to 2 ft. 6 in. high and when the bunch of young flowers as well put out. The object of this operation is to prevent plants wasting their energies in sprouts, shoots, suckling, flowers and seeds.

"Spiking" is an operation which consists in breaking the top at the growing point, inserting a little skewer at the fracture and pushing it a little way down when the tobacco plants are about 1 ft. to 1 ft. 6 in. high. The object of this operation is to *dwarf* the plant, to prevent it throwing out more shoots, and to produce broad and coarse leaves, about ten of which constitute the crop.

"Topping" as described above is practised in America and all other tobacco-growing countries except India where over a considerable tobacco-growing area

[1] *Landw. Versuchs Stat.* 38, p.p. 453-467.

spiking is more commonly adopted. In the Madras Presidency, however, where a good deal of tobacco is used for cigar making, topping as practised in America is carried on. The mass of the tobacco grown in India is consumed in the country by the people themselves for chewing purpose. The object of the cultivator is to grow a heavy crop of coarse tobacco, attention is never paid towards producing a better quality of tobacco suitable for cigar or cigarette making. The reason for this is obvious; there is little or no demand for tobacco of better quality within the country, neither are there agencies for supplying raw materials of better quality in large quantities to Great Britain and other countries for their tobacco factories.

The growers of tobacco are relatively poor men with small capital, their ideas are primitive, they have greater faith in their old practice of spiking because they believe that it brings forth a greater yield of the crop and consequently will fetch more price. The object of the experiment detailed below is to throw light on these two operations by making a study of their comparative effect on the yield and quality of tobacco.

In 1916-17 a number of plants in each of the fourteen plots were simply topped, while others were spiked. Since spiking was carried on earlier than topping, for each spiked plant, chosen for this experiment, another one of the same size and in close proximity to it was selected for topping. All such pairs of spiked and topped plants for experimental purpose were marked with proper labels and consequently there was no difficulty in identifying them when the crop was cut.

The dry weight of leaves and stems of plants from each of the various plots and of each variety (Pusa Type 28 and Surujmukhi) obtained by the two operations are set forth in Table VII given below.

TABLE VII.

Plot	Variety	Spiked		Topped	
		Dry weight of leaves	Dry weight of stems	Dry weight of leaves	Dry weight of stems
		grm.	grm.	grm.	grm.
A	Pusa Type 28	202·3	36·5	187·0	61·7
A_1	Pusa Type 28	195·1	38·3	199·9	42·3
A_1	Surujmukhi	179·5	56·7	147·1	44·4
D	Pusa Type 28	301·5	52·6	247·8	59·0
D_1	Pusa Type 28	149·5	21·4	177·2	29·0
D_1	Surujmukhi	188·6	55·4	168·3	74·3
E_1	Pusa Type 28	201·0	50·7	213·6	50·4
E_1	Surujmukhi	291·4	80·6	259·8	113·0
E_1	Surujmukhi	191·8	72·5	234·0	79·5
	TOTAL .	1906·7	464·7	1834·7	553·6

An examination of the figures in the above statement will show that in 5 cases the spiked plants gave a higher yield in leaves and in 4 cases the topped ones gave a higher yield. Taking the results as a whole, we find that the effect of spiking has been to increase the yield of leaves to a very small extent (4 per cent.) over topping, and the effect of topping has been to increase the weight of stems by 20 per cent. over spiking.

In 1917-18, a plot 30 ft. by 24 ft. was manured with superphosphate and farmyard manure. The manured plot was divided into 4 quadrants each 12 ft. by 15 ft. and in each of these 4 plots, a variety known as Kawnia was transplanted. In two of the diagonally situated plots. all the plants were topped. The spiking was carried on when the plants were 1¼ ft. high as is the common practice in the country. Topping was carried on when the plants were 2 ft. high and young flowers were showing. The average number of leaves to each plant was 12 in case of spiked ones and 14 in case of topped ones.

The results obtained are set out below—

TABLE VIII.

Kawnia Spiked		Kawnia topped	
Dry weight of leaves	Dry weight of stems	Dry weight of leaves	Dry weight of stems
Kilos	Kilos	Kilos	Kilos
3·58	1·039	3·82	1·456
3·37	1·016	3·03	1·337
6·95	2·055	6·85	2·793

An examination of the figures in the above table will show that the yield of tobacco leaves by both the operations (spiking and topping) are almost identical and that the effect of topping has been to increase the yield of stems by about 36 per cent. over spiking. It thus confirms previous year's results.

So far as the quality of tobacco in respect of texture, colour, elasticity, etc., is concerned, Mr. A. C. Acree, Director of the Indian Leaf Tobacco Development Company, Dalsing Sarai, reported the topped ones as decidedly superior to the spiked ones. His report runs as follows :—" In regard to the four samples of Kawnia tobacco my opinion is the tobaccos which have been topped are the best." In the first year three samples of tobacco which were topped and the corresponding three samples which were spiked were submitted to a chemical analysis for those constituents which are commonly recognized as affecting the quality of tobacco. In the following year 1917-18 all the four samples of spiked and topped tobaccos

were examined for the same constituents. The analytical figures obtained in 1917-18 confirmed the previous year's result which points to the conclusion that the relative effects of either topping or spiking on the ash, potash, chlorine and protein contents of tobacco are in no way appreciable, and that topped plants in majority of cases gives a higher nicotine content. These will be evident from an examination of Table IX given below :

TABLE IX.

Samples	Spiked						Topped					
	Pure ash	Potash (K_2O)	Chlorine (Cl)	Amido nitrogen	Albd. nitrogen	Nicotine	Pure ash	Potash (K_2O)	Chlorine (Cl)	Amido nitrogen	Albd. nitrogen	Nicotine
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Average samples of Pusa 28 and Surujmukhi from plot A_1 & D_1	19·87	2·35	0·19	0·277	1·301	3·54	19·74	2·69	0·19	0·248	1·437	4·08
Average samples of Pusa 28 from plots A & D	18·74	3·18	0·68	0·280	1·004	4·60	19·34	3·71	0·84	0·260	0·943	4·29
Average samples of Surujmukhi from Plots E_1 & F_1	19·62	2·82	0·68	0·292	1·195	3·61	19·04	2·30	0·53	0·254	1·290	3·97
Kawnia No. 1, 1917-18 .	17·50	1·82	0·42	0·210	1·080	4·64	16·02	1·80	0·56	0·210	1·090	5·09
Kawnia No. 2, 1917-18 .	15·89	1·93	0·16	0·270	1·100	4·46	16·35	1·81	0·17	0·280	0·970	4·92

A comparative test on the burning capacities of topped and spiked samples of Kawnia grown in the experimental plot were made by Toth's apparatus. The topped sample gave a higher combustion value (650) against the spiked one with a value of 500. When smoked the topped ones burnt better than the spiked ones.

The result of the comparative effect of topping and spiking obtained during two successive years' experiments therefore show that:

(1) The yield of tobacco leaves by both the operations topping and spiking are almost identical.

(2) Topping has the effect of increasing the outturn of stalk and stem, which apart from its value as fuel, has a manurial value too. The stems are also used in snuff making.

(3) Topping has the effect of improving the quality of a tobacco and making it suitable for cigar and cigarette making, whereas spiking produces a tobacco of a coarse, inferior quality and not so suitable for cigar or cigarette making.

(4) There is hardly any difference between topped and spiked tobacco, so far as their ash, potash, chlorine, and protein contents are concerned.

(5) Topped plants in a majority of cases give a higher nicotine content.

(6) Topping produces tobacco of a better burning quality than spiking.

If topping has the effect of improving the quality of a tobacco to such an extent how is it that the Indian ryots and cultivators do not adopt this practice? The reasons are obivious. Firstly, there is little or no demand for such tobacco in this country. Only a few cigarette manufacturing companies now established in India, such as the Peninsular Tobacco Company, Monghyr, are the only concerns which appreciate and demand such a product. Apart from these there are very few agencies in India at present who would deal with such an improved product in the way of supplying other countries. The bulk of tobacco grown is consumed in the country by the people themselves for chewing purpose and topped tobaccos do not as a rule appeal to their tastes. Secondly, the cultivators are under a misapprehension that topped tobacco will always give a lesser yield of leaves by weight and so will fetch a lesser price. In fact, if topping is carried on properly and if on the average fourteen leaves are kept to each plant, topping gives as good a yield as spiking. Pitsch[1] from his experiments conducted at Wageningen, to ascertain the effect on the size and fineness of the leaves of topping to ten, twelve and fourteen leaves per plant, has shown that the total weight of dried leaves on 10 plants, topped to ten, twelve and fourteen leaves, were 422·5, 564·1 and 875·9 grm. respectively. Not only were the total leaves with fourteen leaves the largest but these plants also gave the largest yield of high grade tobacco. He further noticed that the leaves were as a rule larger and thicker when fourteen leaves remained than when twelve were left. In the present experiment 14 leaves were kept to each plant when topped and the size of

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[1] *Deut Landcr. Presse.*, 20 (1895), No 76.

the leaves of the resulting plants were in no way inferior to the leaves from spiked plants. Thirdly, the cultivators here have no idea that topped plants give a much higher outturn of stems which has got a good manurial value as the following analysis of two samples of stems indicate.

	Air-dry tobacco stems, 1917	Air-dry tobacco stems, 1918
	Per cent.	Per cent.
Organic nitrogen	3·07	2·53
Phosphoric acid (P_2O_5)	0·98	0·54
Potash (K_2O)	4·65	4·43

In this connection, Davidson.[1] from his examination of 4 varieties of tobacco, has shown that about one-third of the fertilizing constituents are lost in tobacco stems and roots which should be returned to the soil. Lastly strong tobacco having a high nicotine content finds a good market in this country; the cultivators are under a misapprehension that topping has the effect of always reducing the nicotine content to a great extent; this is hardly the case, as the results of the present experiment indicated.

IV. Ground-curing and Rack-curing.

Ground-curing is the ordinary method of curing tobacco which is generally followed throughout India and is carried out in the following manner.

The plants are cut and allowed to lie on the ground for a couple of days after which they are carried to some grassy spot and laid out so as to be exposed to the sun during the day and to the dew at night, being turned daily. After eight or ten days of this treatment every third or fourth day, the plants are stacked together till they become heated, when they are again spread out to cool.

If at this time sufficient dew does not fall at night a little water is sprinkled over the leaves at evening-time, and this treatment proceeds for twenty days or more. The plants are then brought into cover and stacked; they are turned every third and fourth day, the top going to the bottom and bottom to the top and so on. At this stage, every care is taken to prevent the tobacco getting overheated. If the leaves show a tendency to dry, the heaps are covered with plaintain leaves, over which is placed a blanket or gunnies.

Ground-curing produces tobacco of a dark brown hue and generally of leaves of small elasticity. For cigarettes, this dark brown colour is undesirable and the more this develops, the lower is the value of the product. For Indian market, colour is of very little importance and no care is ever taken to produce tobacco of a light colour.

[1] *Virginia State Bull.* 14, 1892.

Since ground-curing does not produce tobacco of a suitable quality for cigarette manufacture and since flue curing in barn does not suit the local conditions prevailing in this country, the Peninsular Tobacco Company suggested the process known as "rackcuring" which consists of the following operations. Before the crop is harvested the stems are split with a knife, almost to the ground, then cut down and crop left lying on the field for about three hours. When the plants are a little wilted they are inverted and slung on bamboo sticks, so that they just touch one another side ways. The loaded sticks are then hung on bamboo racks provided with a thatched roof made of grass. The tip of the leaves are kept about a foot above the ground, and sufficient space for drying and for free circulation of air is maintained between the rows of loaded sticks as they are placed on the rack. The object of the roof is to protect the plants from dew and rain. When the midribs of the leaves are dry the plants are taken down and the leaves stripped off and bundled. The advantages of this method of curing are evident; there is lesser probability of the leaves being broken and bruised here than is the case with ground-curing where the crop is handled too often, the drying is also slower and the rapid oxidation process in presence of moisture, which changes the colour from yellow to brown, is avoided by protecting the plants from dew.

The object underlying the experiment now under review was to make a comparative study of the changes occurring during the process of curing by these two methods.

In March 1917, a number of plants from one large plot were rack-cured and the rest from the same plot were ground-cured by the ordinary country method. A sample of the rack-cured and one of the ground cured tobaccos of one and the same variety and grown in the same field were obtained from the Indian Leaf Development Company, Dalsing Sarai. These four samples of tobacco (two ground-cured and two rack-cured) were analysed for their ash, potash, chlorine, amido nitrogen and nicotine contents. An examination of these samples (Table X) showed that excepting the nicotine the other constituents were hardly affected.

TABLE X.

Constituents	Tobacco from Dalsing Sarai		Tobacco from Pusa Pot Culture House	
	Rack-cured	Ground-cured	Rack-cured	Ground-cured
	Per cent.	Per cent.	Per cent.	Per cent.
Nicotine	2·25	2·65	2·79	3·59
Pure ash	19·37	16·95	17·66	19·70
Potash as K_2O	3·17	2·82	3·46	3·17
Chloride as Cl	0·75	1·90	0·29	0·36
Amido nitrogen	0·25	0·32	0·17	0·13

The results tabulated in Table X indicate that rack-curing has the effect of reducing the nicotine content appreciably. The reduction of nicotine (specially the volatile nicotine) in the tobacco by rack-curing may also account for the suitability of such tobacco for cigarette manufacture.

Garner [1] has shown that nicotine exists in two forms in tobacco, one of which is easily volatile and readily soluble in petroleum ether, while the other is volatile only at elevated temperatures and is almost insoluble in petroleum ether. He has further shown that the undesirable sharpness or pungency contained in the smoke of certain types of cigar filler tobacco is due almost entirely to the volatile easily soluble form of nicotine which acts, as if it were, in the free state. The pungent harsh quality of smoke is partially but not entirely removed by protracted resweating and aging of the tobacco, whereby easily volatile nicotine is largely expelled. It would, therefore, appear that during the process of curing on rack, owing to the free circulation of air round the plants and slow drying of the tobacco, a large proportion of the so-called volatile nicotine, which gives the undesirable sharpness or pungency to the smoke from certain types of tobacco, is expelled and the quality, improved thereby.

With a view to obtain confirmation of these results and ascertain how much of the sugar and starch of tobacco are consumed during the process of rack-curing and ground-curing, estimations were made on tobacco cured by both these processes during 1918. For this purpose, two samples of rack-cured and two samples of ground-cured tobaccos were prepared and examined. The results are set forth in Table XI and show that, as in the previous year, the ash, potash and amido nitrogen were practically unaffected by any of the two processes, but that the effect of rack-curing was to reduce appreciably the nicotine content.

TABLE XI.

Constituents	Tobacco plot B		Tobacco plot D	
	Rack-cured	Ground-cured	Rack-cured	Ground-cured
	Per cent.	Per cent.	Per cent.	Per cent.
Nicotine	4·28	4·54	4·84	5·85
Pure ash	17·68	17·22	17·74	17·17
Potash (K_2O)	3·11	2·97	2·27	2·40
Chlorine (Cl)	..	0·22	0·39	0·42
Amido nitrogen	0·296	0·232	0·206	0·248

[1] *U. S. Dept. of Agri. Bureau of Plant Industry, Bull.* 141, Pt. I.

In order to test the efficacy of rack-curing in removing a portion of the so-called volatile nicotine, samples of tobacco latterly cured by the ground and the rack processes were extracted with petroleum ether and ether successively (the petroleum ether dissolving the volatile nicotine and the ether the total nicotine), and volatile and Fixed nicotine determined in the extract. A brief summary of the results obtained is given in the following table. :—

TABLE XII.

Constituents	Sample 1		Sample 2	
	Ground-cured	Rack-cured	Ground-cured	Rack-cured
	Per cent.	Per cent.	Per cent.	Per cent.
Volatile nicotine	1·74	1·57	2·53	2·27
Fixed nicotine	3·11	3·06	0·91	0·98

A comparison of the results obtained clearly shows that ground-cured tobacco gives a higher content of volatile nicotine than rack-cured ones ; that is to say, rack-curing is more effective than groundcuring in reducing the volatile nicotine.

Estimation of the sugar content of tobacco in fresh samples before curing and in the corresponding cured samples indicated that the proportion of reducing sugar to the total sugar increases in both the processes but the amount of total sugar consumed by both these processes of curing is quite irregular.

With regard to the starch, the rack-cured tobaccos showed a higher content than those cured on ground or in other words the destruction of starch was greater in case of ground-cured tobaccos than those cured on racks as is evident from the following table :—

TABLE XIII.

Description of samples	Fresh sample starch	Rack-cured starch	Ground-cured starch
	Per cent.	Per cent.	Per cent.
Sample B-P	4·81	3·73	2·23
Sample D_1-P	6·34	3·52	3·29

Studies on tobacco curing by these two processes have thus shown that—

(1) Rack-curing produces tobacco of a bright yellow colour quite suitable for cigarette manufacture, while ground-curing produces tobacco of dark brown hue.

(2) Rack-cured tobacco leaves possess greater elasticity than ground-cured leaves and hence suit better for cigarette making.

(3) Rack-curing has the effect of reducing the nicotine content and specially of the volatile nicotine and it is this constituent which gives an undesirable sharpness or pungency to the smoke.

(4) Rack-curing produces tobacco with a higher starch content than those cured on ground.

Though rack-curing has so many advantages over the ground-curing process, the disadvantages attending it are in no way less. Rack-curing entails a good deal of expense and supervision as has been pointed by Howard and Howard[1] in the following words:—" A considerable amount of labour and expense are involved in the errection of the curing racks. The curing process is a long one and the crop is on the rack for at least six weeks, during which it is liable to damage by wind, rain and hail. Towards the end of the process, the danger of fire has to be guarded against. A good deal of supervision is required when the cured plants are taken off the racks and the leaves are stripped and baled."

The disadvantages attending the ground-curing method to produce a tobacco more suitable for cigarette manufacture are chiefly two: firstly, it produces tobacco of a dark brown hue, and, secondly, ground-cured tobacco leaves are harsh to the feel and possess less elasticity. As regards the latter, if damage to the leaves and stalks is avoided as far as possible by carefully handling the crop when spreading and stacking it and if the tobacco is not dried too fast, it will produce leaves possessing good elasticity.

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[1] *Pusa Agri. Res. Inst. Bull.* 50.

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Memoirs of the Department of Agriculture in India

The Determination of Available Phosphoric Acid of Calcareous Soils

Part I. Inapplicability of Dyer's Method to Highly Calcareous Soils

Part II. Extraction of Phosphoric Acid of Calcareous Soils with Salt Solutions

Part III. Potassium Carbonate Method for Estimation of Available Phosphoric Acid of Highly Calcareous Soils

BY

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

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THE DETERMINATION OF AVAILABLE PHOSPHORIC ACID OF CALCAREOUS SOILS.

PART I.

Inapplicability of Dyer's Method to Highly Calcareous Soils.

BY

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(Received for publication on 9th June 1925.)

The value of weak acid solvents has generally been recognized by all agricultural chemists as a means of evaluating the "available" potash and phosphoric acid in soils. The importance of this method of analysis lies in the fact that it affords a distinction between those phosphorous compounds which are fairly easily soluble and may therefore be expected to become readily available as plant food, and the less soluble compounds which are of less value to the nutrition of plants. But it is generally conceded that the method is an empirical one, and its usefulness lies in the correlation of the analytical values obtained with the response of ordinary soils to a manurial treatment based on these values.

The method had its origin in the conception of the plant root as a special excreting agent capable of liberating acids which attack the soil constituents, and, by dissolving them, bring them into a form to be readily assimilated by the plant. With this conception in view Dyer[1] examined the root-sap acidity of 20 different natural orders of plants and found it to be on the average 0·91 per cent. in terms of citric acid. He, therefore, proposed 1 per cent. citric acid solution as the standard to be employed for the estimation of available potash and phosphoric acid in soils. Since then the use of citric acid has been widely accepted for this purpose, although in later years other acids of different strengths have come into use.

The conception of the plant root as an excreting and dissolving agent which gave rise to the above methods is now generally abandoned, as no trustworthy evidence can be obtained that any acid other than carbon dioxide is excreted, or that any action beyond respiration is concerned. However, the general principle underlying them is the extraction of soils with acids of low concentration, and their value lies in their correlation with the results of cropping and manurial treatments.

[1] *Trans. Chem. Soc.*, 1894, **65**, 115.

The application of Dyer's method of analysis to highly calcareous soils results in the neutralization of much of the citric acid used, and the values obtained in these circumstances have been received with suspicion by many chemists. Dyer himself, in a postscript to his paper (loc. cit.), recommended that in such cases an extra amount of citric acid equivalent to the quantity of calcium carbonate present might reasonably be added to the solution.

Wood[1] and Leather[2], when employing such extra amount of acid, found that the results obtained were not borne out by actual farm practice or pot-cultures; but Cousins and Hammond[3], from experiments on bananas, adduce evidence diametrically opposed to their conclusion. Stenius[4], using extra amount of citric acid, found that the basicity has a decidedly depressing influence on the solvent power of citric acid for available P_2O_5. His results do not lend support to the contentions of Cousins and Hammond.

Hall and Plymen[5] added to soils 2-10 per cent. calcium carbonate as finely-powdered Iceland Spar, and found that the citric acid, as it was neutralized by $CaCO_3$, extracted less and less phosphoric acid, until with 10 per cent. $CaCO_3$, which is more than what is required for complete neutrality, the amount dissolved approximated to that dissolved from the soil by carbon dioxide alone. They held that in the light of more extended experience it might be found necessary to adopt different limits for soils of different types.

Sen[6], following a similar line of investigation, demonstrated that the addition of increasing amounts of $CaCO_3$ to non-calcareous soils resulted in decreasing amounts of P_2O_5 being extracted by 1 per cent. citric acid solution, and concluded that the method could not be relied upon to determine the limits of fertility of calcareous soils.

Similarly, Ramsay[7] found that the presence of $CaCO_3$ in tricalcium phosphate materially reduced the percentage of P_2O_5 extracted when the standard method of extraction with citric acid was applied to the mixtures.

Davis[8], in his study of the calcareous soils of Bihar, has shown that soils containing practically the same amounts of lime may give extraordinary differences in the values of available P_2O_5 extracted by Dyer's method and that soils with a very high proportion of lime may give much higher values than soils with a far smaller proportion of lime. He thus holds the opinion that the varying values obtained with such calcareous soils give a good indication of their fertility and probable manurial reaction. This argument is not, however, convincing, for the fact remains that the majority of North Bihar calcareous soils yield such extremely

[1] *Trans Chem. Soc.*, 1896, 287.
[2] *Mem. Dept. Agri. India, Chem. Series*, Vol. I, No. 4, 1907.
[3] *Analyst*, 1903, **28**, 230.
[4] *Jour. Indus. and Engin. Chem.*, March 1, 1919.
[5] *Trans. Chem. Soc.*, 1902, 117-144.
[6] *Agri. Jour. India*, April, 1917.
[7] *Jour. Agri. Sc.*, Vol. IX, 1917.
[8] *Indigo Publication* No. 1, Pusa, 1918.

low values of available phosphoric acid that if any reliance has to be placed upon them, the action of phosphatic manures on them should be well defined and distinctly positive, whereas in actual farm practice it is found that their action is extremely erratic. The application of superphosphate alone, more often than not, yields disappointing results, and the best yields are usually obtained in conjunction with green-manuring.

The trend of such observations as are available, judged in the light of experience, led the writer to the conclusion that with highly calcareous soils there is no definite correlation between the available phosphoric acid determined by Dyer's method and the manurial reactions obtained, and that the method is of very dubious value under these conditions. This should be obvious from a consideration of the facts that the composition of the extracting liquid changes considerably in character with the proportions of $CaCO_3$ present, and that, as shown by Hall and Amos[1], the amount of a soil constituent which passes into solution depends not only on its nature, but also on its mass.

The composition of the extract of a soil when treated with any solvent depends upon the following factors :—

1. The mass of the mineral constituents exposed to the solvent and their solubility under the conditions of the extraction, and the nature of the solvent.
2. The effect of the solvent upon the soil particles protecting or enclosing the minerals.
3. The power of the soil to fix or adsorb the dissolved substances from the solution.

Consequently, it appeared desirable to make a more detailed study of the effect of increasing proportions of $CaCO_3$ in a soil on the amounts of the "available" phosphoric acid determined by Dyer's method than had been done by Sen (loc. cit). The latter increased the proportions of added $CaCO_3$ by increments of 5 per cent. up to a maximum of 10 per cent., but in the present investigation these increments were materially decreased so as to follow the effect more closely up to a maximum addition of 25 per cent.

The soil selected was obtained from Kalianpur and was found to contain a considerable amount of available P_2O_5 as determined by Dyer's method and a very small proportion of $CaCO_3$. The physical and chemical characteristics of this soil as well as of the Pusa soil employed in this investigation are given in a paper published by Harrison and Das[2]. At the same time Sen's experiments of mixing Kalianpur and Pusa soils were repeated, but in this case the available potash was not estimated.

The results obtained from the application of Dyer's method to the several mixtures are given in the following tables.

---

[1] *Trans. Chem. Soc.*, 1906, **89**, 205.
[2] *Mem. Dept. Agri., India, Chem. Series*, Vol. V, No. 9, 1921, 210-211.

TABLE I.

Showing the effect of increasing proportions of $CaCO_3$ added to Kalianpur soil on the available P_2O_5 and K_2O extracted by Dyer's method.

Per cent. $CaCO_3$	Grm. available P_2O_5 per 100 grm. mixture (*found*)	Available P_2O_5 present (*calculated*)	Per cent. P_2O_5 extracted	Grm. available K_2O per 100 grm. mixture (*found*)	Available K_2O present (*calculated*)	Per cent. K_2O extracted
0	0·3313	—	100·0	0·0344	—	100·0
2	0·2690	0·3276	82·1	0·0290	0·0337	86·1
4	0·2046	0·3206	64·1	0·0264	0·0330	80·0
5	0·1835	0·3176	57·8	0·0239	0·0327	73·1
6	0·1279	0·3142	40·7	0·0199	0·0323	61·6
7	0·0363	0·3109	11·7	0·0142	0·0320	44·4
8	0·0257	0·3076	8·4	0·0160	0·0316	50·6
9	0·0231	0·3042	7·6	0·0153	0·0313	48·9
10	0·0191	0·3009	6·4	0·0142	0·0310	45·8
12	0·0109	0·2942	3·7	0·0152	0·0303	50·2
14	0·0088	0·2875	3·1	0·0155	0·0296	52·4
16	0·0049	0·2808	1·7	0·0147	0·0289	50·9
18	0·0031	0·2741	1·1	0·0157	0·0282	55·7
20	0·0025	0·2674	0·9	0·0141	0·0275	51·3
25	0·0017	0·2507	0·7	0·0134	0·0258	52·0

In the above experiments the Kalianpur soil was mixed with pure $CaCO_3$ containing no P_2O_5 and the comparisons are therefore easy to determine. In the case of the experiments where the Kalianpur soil was mixed with Pusa soil, the amount of P_2O_5 extracted from the mixtures becomes a proportion of the two soils and the comparisons are not so easy to determine. The results obtained are given in the following table.

TABLE II.

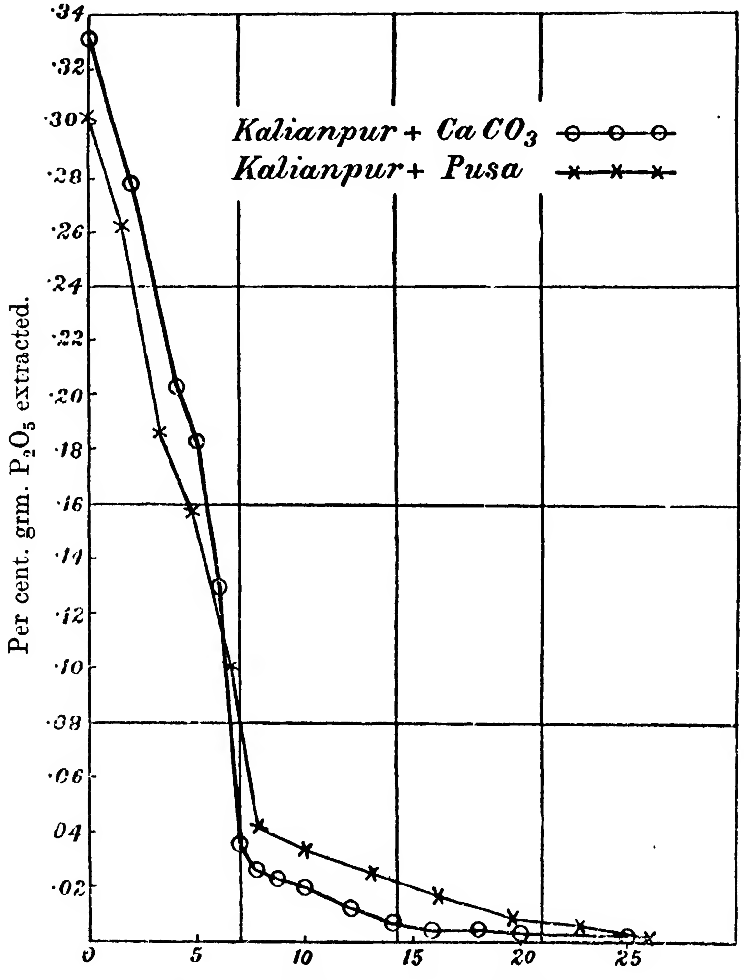
Showing the effect of increasing proportions of Pusa soil added to Kalianpur soil on the available P_2O_5 extracted by Dyer's method.

Per cent. Kalianpur soil	Per cent. Pusa soil	Per cent. $CaCO_3$ equivalent to per cent. Pusa soil in the mixture	Per cent. available P_2O_5 in soil mixture (*found*)	Per cent. available P_2O_5 from 1st and last experiments (*calculated*)	Per cent. P_2O_5 extracted
100	nil	(*in Kalianpur soil* 0·28)	0·3034	—	100·0
95	5	1·63	0·2628	0·2889	91·0
90	10	3·25	0·1852	0·2743	67·5
85	15	4·88	0·1586	0·2598	62·7
80	20	6·50	0·1005	0·2452	41·0
75	25	8·13	0·0410	0·2307	17·7
70	30	9·75	0·0353	0·2161	16·4
60	40	13·00	0·0250	0·1870	13·1
50	50	16·25	0·0158	0·1579	10·0
40	60	19·50	0·0085	0·1288	6·6
30	70	22·75	0·0061	0·0997	6·1
20	80	26·00	0·0028	0·0706	4·0
Nil	100	32·50	0·0004	0·0124	3·2
Nil*	100	32·50	0·0124	0·0124	100·0

* In this experiment sufficient citric acid (*i.e.*, 45·46 grm.) to neutralize 32·5 grm. of $CaCO_3$ present in the soil + 1 per cent excess citric acid, all dissolved in 1 litre solution, was used.

DIAGRAM I.

Showing the curves produced by plotting per cent. $CaCO_3$ present as such or in the form of Pusa soil in the mixtures against per cent P_2O_5 extracted.



Per cent. $CaCO_3$ present in mixture.

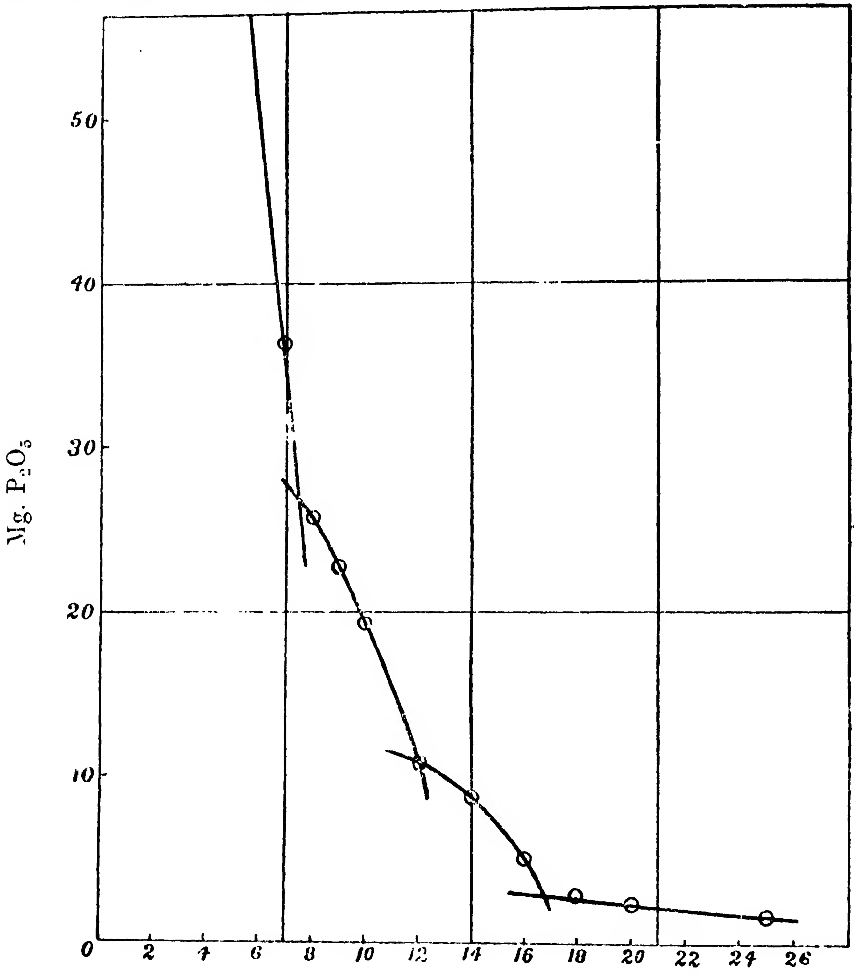
The curves very clearly show the similarity of the results obtained when the $CaCO_3$ is added as such or in the form of Pusa soil. It is evident that the main determining factor is the amount of $CaCO_3$ present, but the continuity of effect is not apparent.

It is found that there is a rapid falling off in the amount of P_2O_5 extracted until there is between 7 and 8 per cent $CaCO_3$ present, above which value the reduction becomes less pronounced.

When, however, the values obtained with over 7 per cent. $CaCO_3$ present are plotted on a larger scale, the breaks in the curve are made more pronounced. This is shown in the following diagram.

DIAGRAM II.

Showing a larger scale plotting of the P_2O_5 extracted against per cent. $CaCO_3$ present.



The broken nature of the curve suggests that the values obtained for P_2O_5 vary according to the character of the solvent solution, and it is possible from the curves to approximately determine the phases which control the extractions concerned. With gradually increasing amounts of $CaCO_3$ the solutions resulting from the inter-

action of $CaCO_3$ with a citric acid solution of definite volume and strength show the following changes :—

1. A strongly acid solution.
2. A series of solutions of decreasing acidity with increasing amounts of CO_2 and saturated with respect to calcium citrate, up to about 7 per cent. $CaCO_3$, marking the point at which the citric acid is completely neutralized.
3. A saturated solution of calcium citrate with decreasing amounts of free CO_2 and increasing proportion of calcium bicarbonate, from about 7-12 per cent. $CaCO_3$.
4. A saturated solution of calcium citrate with increasing concentration of calcium bicarbonate, from about 12-16 per cent. $CaCO_3$.
5. A solution of approximately constant composition with respect to calcium citrate and bicarbonate, from 16-25 per cent. $CaCO_3$ or upwards.

It will be shown in the sequel that the extraction of the Kalianpur soil with solvents approximating in composition to the phases mentioned above yields results commensurate with those obtained from the corresponding soil mixtures. For the present, however, it may be taken that the application of the Dyer's method for the estimation of available phosphoric acid in calcareous soils is, in effect, an extraction with a series of dissimilar solutions, the composition of which depends mainly upon the amount of $CaCO_3$ present.

When the composition of these solutions is carefully considered in detail, it is evident that two main phases are concerned :

(i) A phase of decreasing acidity with an approximately constant Ca-ion concentration ; and

(ii) A phase of a series of solutions with an increasing Ca-ion concentration.

It would seem probable, therefore, that by plotting the logarithm of the percentage of $CaCO_3$ against the logarithm of milligrams P_2O_5, two definite curves would be produced. That this is the case is shown in the following diagram.

The graph, which consists of two distinct parts, clearly shows that the extraction of the P_2O_5 is not affected by a uniform set of factors, but that one set of factors operate up to the point when the percentage of $CaCO_3$ reaches between 6 and 7 per cent., and above this point a different set of factors affect the extraction. The variations of individual determinations from the straight line curve may also be considered to be due to the minor changes of composition in the several solutions.

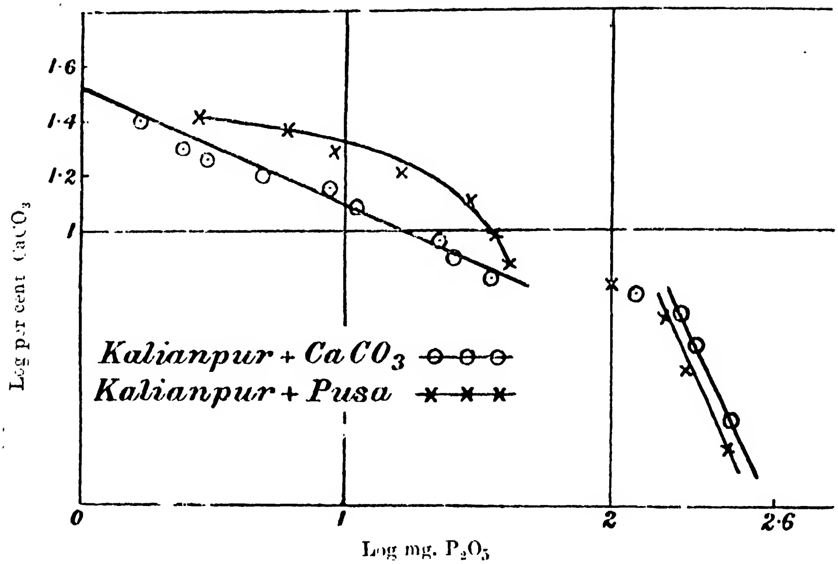
From this it follows that in the case of mixtures of Kalianpur soil with $CaCO_3$ the changes are approximately governed by the mathematical relation

$$\log P = a - b \log C,$$

where P = mg. P_2O_5 extracted,
C = per cent. $CaCO_3$ present, and
a and b are constants.

DIAGRAM III.

Showing the curves produced by plotting log per cent. $CaCO_3$ against log mg P_2O_5.



In the *first stage* the values for a and b are 2·573 and 0·4963, and for the *second stage* 3·155 and 2·267 respectively. The variations between the experimental and the calculated values are shown in the following table.

TABLE III.

Showing the calculated and the experimental values of P_2O_5 extracted from mixtures of Kalianpur soil with $CaCO_3$.

Per cent. $CaCO_3$	P_2O_5 calculated	P_2O_5 found	Difference
1st stage. log P 2·573– 0·4963 log C			
2	0·2652	0·2690	+0·0038
4	0·1881	0·2046	+0·0165
5	0·1683	0·1835	+0·0152
6	0·1537	0·1279	—0·0258
2nd stage. log P =3·455 —2·267 log C			
7	0·0346	0·0363	+0·0017
8	0·0256	0·0257	+0·0001
9	0·0196	0·0231	+0·0035
10	0·0154	0.0194	+ 0.0040
12	0·0102	0·0109	+0·0007
14	0·0072	0·0088	+0·0016
16	0·0053	0·0049	—0·0004
18	0·0041	0·0031	- 0·0010
20	0·0032	0·0025	—0·0007
25	0·0019	0·0017	—0·0002

The mathematical relation given above is capable of being expressed as follows :—

$$P = A.C^{-b}$$

or

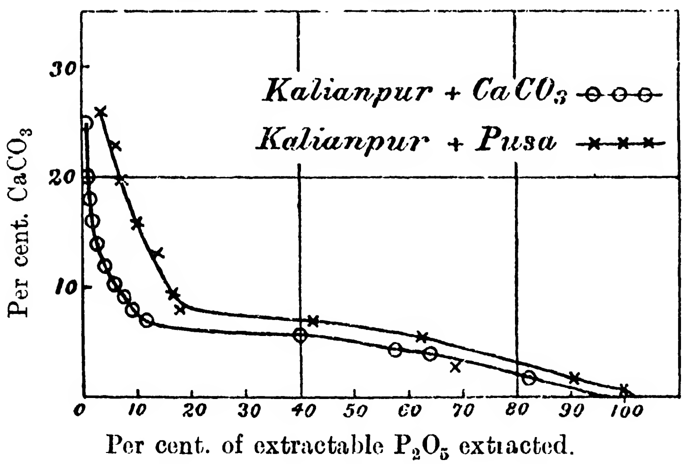
$$P.C^{b} = A.$$

This resembles the well-known Poisson's equation for the adiabatic expansion f gases. The curve produced on plotting P against C as shown in Diagram I onforms approximately to this equation.

In the case of mixtures of Kalianpur and Pusa soils a relationship of this type s not apparent, but it should be borne in mind that the latter soil itself contains n appreciable amount of P_2O_5, which is extractable by solution containing free itric acid. Therefore, the experimental results are subject to the effect of factors which do not operate in the case of mixtures of Kalianpur soil with $CaCO_3$. Nevertheless, it is evident that the main determining factor in both cases is the proportion of $CaCO_3$ present. This is also confirmed when the per cent. of extractable P_2O_5 extracted from both kinds of mixtures is plotted against the values of per cent. $CaCO_3$ present as such or in the form of Pusa soil, from Tables I and II respectively. The following diagram demonstrates this.

DIAGRAM IV.

Showing the curves produced by plotting per cent. $CaCO_3$ present against per cent. of extractable P_2O_5 actually extracted.



That adsorption does not control the phenomena is demonstrated by the fact hat the amount of P_2O_5 extracted varies according to the time of extraction, all ther things being equal. The results are shown in the following table.

TABLE IV.

Showing the effect of time on the extraction of P_2O_5 by Dyer's method.

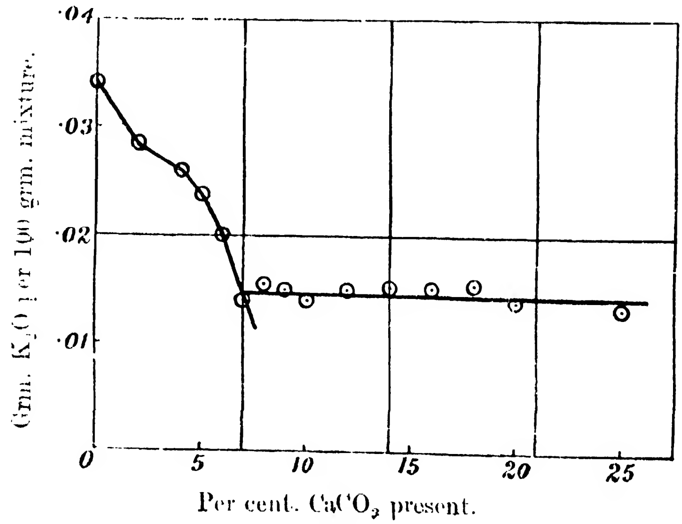
Per cent. $CaCO_3$ in soil mixture	P_2O_5 extracted per 100 grm. soil mixture	
	By 24 hours' shaking	By 48 hours' shaking
7	0·0363	0·0227
8	0·0257	0·0177
9	0·0231	0·0136
10	0·0191	0·0109
12	0·0109	0·0051
14	0·0088	0·0048

That is to say, the increased time of extraction leads to a decided reduction in the amount of P_2O_5 extracted, and this is not evidently due to adsorption phenomenon, but to an increased Ca ion concentration in the solvent. The effect of the presence of $CaCO_3$ on the extraction of P_2O_5 is, therefore, mainly chemical in character.

Turning now to the figures in Table I for the available K_2O extracted, it is obvious that there is a falling off in the values obtained up to about 7 per cent. $CaCO_3$ present in the soil mixture, and beyond that the rate of reduction is hardly appreciable. This is shown in the following diagram.

DIAGRAM V.

Showing the effect of increasing proportions of $CaCO_3$ on the available K_2O extracted from Kalianpur soil by Dyer's method.



When the values for K_2O are carefully examined, it is evident that there is a gradual reduction in the amount extracted with the decreasing acidity of the solvent during the first stage up to about 7 per cent. $CaCO_3$ present, marking the point at which all the citric acid used is completely neutralized and afterwards the amount of K_2O extracted is practically constant with the almost neutral character of solvent produced.

Consequently, the presence of larger proportions of $CaCO_3$ than 7 per cent. has a much smaller effect on the K_2O values than is the case with P_2O_5, and the validity of Dyer's method applied to calcareous soils is not materially affected in its relation to available K_2O beyond the stage of 7 per cent. $CaCO_3$ present.

Finally, the following table shows that the extraction of the Kalianpur soil with solvents approximating in composition to those produced with varying proportions of $CaCO_3$ yields comparable values.

TABLE V.

Showing the amounts of P_2O_5 and K_2O extracted from Kalianpur soil with solvents corresponding to the phases produced with varying proportions of $CaCO_3$.

Solvent	Per cent. P_2O_5 extracted	Per cent. K_2O extracted	With corresponding phase by Dyer's method	
			Per cent. available P_2O_5	Per cent. available K_2O
Saturated solution of calcium citrate + CO_2	0·0069	0·0160	0·0363	0·0142
Saturated solution of calcium citrate + calcium bicarbonate.	0·0012	0·0149	0·0025	0·0141

Hence, the conclusion emerges that the application of Dyer's method to calcareous soils results in the employment of solvents varying in composition according to the amount of $CaCO_3$ present.

Further, an extraction was made of the Pusa soil with 1 per cent. citric acid solution after neutralizing the $CaCO_3$ present with extra amounts of citric acid as was suggested by Dyer in the postscript of his paper (loc. cit.).

As 7·15 grm. of $CaCO_3$ are neutralized by 10 grm. of citric acid according to the equation -

$$2\begin{matrix} C_1H_2.COOH \\ C_1.(OH).COOH,\ H_2O \\ CH_2.COOH \end{matrix} + 3\,CaCO_3 = (C_6H_5O_7)_2Ca_3, 4H_2O + 3CO_2 + H_2O$$

$2 \times 210 = 420$ $3 \times 100 = 300$

Citric acid.   Calcium carbonate   Calcium citrate.

The 32·57 grm. of $CaCO_3$ present in 100 grm. of Pusa soil taken for the experiment will require 15·6 grm. of citric acid for complete neutralization, and consequently, while making the extraction, this amount of citric acid was dissolved in a litre of 1 per cent. citric acid solution. No allowance was, however, made for other basic substances, such as, Fe, Al, Mg, etc., present which might consume some of the citric acid for their solution. The results are shown in the following table and compared with those obtained with 1 per cent. citric acid solution alone.

Table VI.

Showing the amounts of P_2O_5 and K_2O extracted from Pusa soil by the original and the modified method of Dyer.

Solvent used	Per cent. P_2O_5 extracted	Per cent. K_2O extracted
1 per cent. citric acid solution alone (*original method*).	0·0003	0·0109
1 per cent. citric acid solution + sufficient citric acid to neutralize $CaCO_3$ present (*modified method*).	0·0154	0·0185

The value of P_2O_5 obtained with extra amount of citric acid as suggested by Dyer (loc. cit.) for calcareous soils, although considerably higher than Dyer's limiting figure of 0·01 per cent. P_2O_5, does not agree with the known manurial reactions of the Pusa soil and such other calcareous soils of Bihar. Hence, Dyer's contention breaks down in such cases as a discriminating agent.

Incidentally, it may be mentioned that Leather published the results of similar experiments a few years ago (loc. cit.) with a Pusa soil containing 38·63 per cent. $CaCO_3$. His figures for potash and phosphoric acid are unexpectedly lower than those I have obtained under similar experimental conditions. This is obviously due to the fact that he took 10 grm. of citric acid as being equivalent to 14·30 grm. of $CaCO_3$ instead of the correct amount of 7·15 grm. (see p. 46 of Leather's paper).

Summary and Conclusions.

1. Dyer's method breaks down as a means of estimating available phosphoric acid in calcareous soils. The application of 1 per cent. citric acid solvent in such cases is, in effect, an extraction with a series of dissimilar solutions, the composition of which depends mainly upon the $CaCO_3$ content of the soils.

2. In the case of available potash Dyer's method is at least unsuitable for those soils whose $CaCO_3$ content ranges from 1—7 per cent., beyond which, however, the extraction of potash is not materially affected by the presence of $CaCO_3$.

3. The suggestion made by Dyer for the use of an extra amount of citric acid to neutralize the $CaCO_3$ present in calcareous soils in addition to the usual 1 per cent. citric acid solution, produces results which are not correlated with the known manurial reactions of such soils.

4. This being the case, the values obtained by Dyer's method in the case of calcareous soils of varying $CaCO_3$ content cannot be correlated with one another, and far less so with non-calcareous soils. Consequently, the method must be looked upon with suspicion, until a rigorous correlation of the analytical data with definite manurial reactions of the soils under examination can be obtained.

PART II.

Extraction of Phosphoric Acid of Calcareous Soils with Salt Solutions.

In Part I it has been demonstrated that the presence of $CaCO_3$ interferes considerably with the estimation of available plant food in calcareous soils by Dyer's method (loc. cit.), and consequently renders the application of 1 per cent. citric acid solvent in such cases of dubious value. This being the case, the employment of such a solvent as is not appreciably affected by the presence of $CaCO_3$ is rendered necessary in order to secure a reliable indication of the fertility of these soils in relation to available plant food.

Most investigators who have proposed methods of determining available plant food in soils have employed an acid of weak concentration as the solvent. For example, dilute HCl, HNO_3 and CH_3. COOH of indefinite strength were proposed in the earliest papers on this subject by Liebig,[1] Deherain,[2] Vogel,[3] and Dugast[4]. 1 per cent. citric acid solution was proposed by Tollens[5], Ollech[6], Stutzer,[7] Thomson,[8] and Dyer[9], whereas Eggertz and Nilson[10], and Wiklund[11] used 2 per cent. HCl, *i.e.*, of about N/1·82 strength. The American Association of Official Agricultural Chemists prefers the use of fifth-normal HCl or HNO_3 for this purpose, whereas Moore[12] proposed N/200 HCl, Maxwell[13] 1 per cent aspartic acid, Schloesing, Jun.[14] dilute HNO_3 of various strengths, and Emmerling[15] 1 per cent. oxalic acid. On the other hand, Mitscherlich[16], Schloesing,[17] and Garlach[18] thought that the natural solvent of any theoretical interest is that of carbon dioxide only, which is excreted in the process of respiration by plants, and therefore proposed an aqueous solution of CO_2 as the solvent for estimating available plant food in soils.

A very few workers, however, have used alkaline or neutral salt solutions. For instance, Petermann[19] employed ammoniacal solution of ammonium citrate, Hoffmeister[20] ammoniacal solution of humic acid, Dugast[21] solutions of ammonium

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[1] *Zeit. d. Landw. Ver.*, 1872.
[2] *Ann. Agron*, 1881, **6**, 392-393; *ibid.*, **17**, 445-454.
[3] *Bied. Centr.*, 1882, 852.
[4] *Ann. Agron*, **9**, 470-478.
[5] *Ber. d. deutsch. Chem. Gesell.*, 1880, **13**, 1267.
[6] *Journ. f. Landw.*, 1882, **30**, 519.
[7] *Chem. Ind.*, 1884, **7**, 37.
[8] *Ibid.*, 1885.
[9] *Trans. Chem. Soc.*, 1894, **65**, 115-167; and also *Phil. Trans.*, 1901, **194B**, 235-290.
[10] *Bied. Centr.*, 1889, 664-668.
[11] *Landw. Jahrb.*, 1892, **20**, 909-928.
[12] *Journ. Amer. Chem. Soc.*, 1912, 791.
[13] *Ibid.*, 1899, **21**, 4-15.
[14] *Compt. rend.*, 1899, **128**, 1004.
[15] *Bied. Centr.*, 1900, **29**, 75.
[16] *Landw. Jahrb.*, 1907, **36**, 309-369.
[17] *Compt. rend.*, 1900, **131**, 149.
[18] *Landw. Versuchs. Stat.*, 1896, **46**, 201.
[19] *Recherches der chimie et Physiologie*, 1898, **3**, 59.
[20] *Landw. Versuchs. Stat.*, 1898, **50**, 363.
[21] *Ann. Agron.*, 1884, **9**, 470-478.

oxalate, ammonium citrate, and also water, and Lechartier[1] 2 per cent. ammonium oxalate.

It has been generally recognized that some solvent weaker than strong mineral acid should be employed in the analysis of soils in order to obtain an indication of the proportion of available mineral plant food. Most of the suggestions made, however, have been arbitrary in the sense of not having any definite basis beyond the recognized necessity that the solvent should be a weak one.

It is obvious that the employment of ordinary acids will bring about a reaction with the calcium carbonate present in calcareous soils and introduce calcium-ions in the extracting liquid, which will tend to depress the concentration of P_2O_5 ions in the solution.

This being the case, it appeared desirable to make a study of the action of various salt solutions on the solubility of the phosphates of calcareous soils in order to find one which is not affected by varying amounts of $CaCO_3$. In this connection the study must also extend to the discovery of a solvent which is capable of dissolving such quantities of P_2O_5 as will not give rise to manipulative and analytical difficulties.

The same Kalianpur and Pusa soils as were used in Part I were also employed for this investigation.

Those salt solutions were chosen which probably would not be appreciably affected by the presence of $CaCO_3$.

Method of experiments. 100 grm. of various soil mixtures with $CaCO_3$ or Pusa soil were shaken with a litre of the solvent for 24 hours as in the case of Dyer's method in a mechanical shaker in end-over end rotations in a room which was not subjected to sudden changes of temperature. After separating the extract by suction, the dissolved P_2O_5 was determined in the usual way by the molybdate ammonium method. In some cases the dissolved K_2O was determined by the platinic chloride method.

1. EXTRACTION WITH 1 PER CENT. NEUTRAL AMMONIUM CITRATE SOLUTION (N/8 STRENGTH).

TABLE I.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. neutral ammonium citrate solution and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture		Grm. K_2O per 100 grm. mixture	
		Found	Calculated	Found	Calculated
		A.—Kalianpur soil + $CaCO_3$			
100	nil	0·0459	.	0·0359	—
95	5	0·0077	0·0436	0·0363	0·0341
90	10	0·0059	0·0413	0·0332	0·0323
85	15	0·0051	0·0390	0·0320	0·0305
80	20	0·0041	0·0367	0·0303	0·0287
75	25	0·0041	0·0344	0·0283	0·0269
70	30	0·0038	0·0321	0·0269	0·0251

[1] *Compt. rend.*, 1884, **98**, 1058-1061.

TABLE I—*concld.*

Grm. Kalianpur soil taken	Grm. Pusa soil added	Grm. P_2O_5 per 100 grm. mixture		Grm. K_2O per 100 grm. mixture	
		Found	Calculated	Found	Calculated
		B. Kalianpur soil + Pusa soil			
100	nil	0·0459	-	0·0359	-
95	5	0·0048	0·0436	0·0356	0·0349
90	10	0·0037	0·0416	0·0336	0·0338
85	15	0·0032	0·0391	0·0308	0·0327
80	20	0·0037	0·0369	0·0306	0·0317
75	25	0·0035	0·0346	0·0303	0·0306
70	30	0·0023	0·0324	0·0294	0·0295
nil	100	0·00086	0·00086	0·01467	0·01467

The extracts obtained were all brown in appearance, showing that an appreciable amount of organic matter was dissolved out. It is obvious that the presence of $CaCO_3$ in any form has depressed the solubility of the soil phosphates. Similar results were obtained by Harrison and Das[1], who found that $CaCO_3$ added to a saturated solution of dicalcic phosphate in 1 per cent. neutral ammonium citrate rendered insoluble some of the P_2O_5 from the solution under similar conditions. Further, it is evident that the effect of adding Pusa soil to the mixture on the extraction of P_2O_5 is much more depressing than pure $CaCO_3$. In the case of the extraction with an acid solvent such as the 1 per cent. citric acid solution the effect was just the reverse. Here, in the case of mixtures with Pusa soil evidently other factors come into play which do not operate in the case of the mixtures of Kalianpur soil with $CaCO_3$ and which bring about a greater reduction in the amount of P_2O_5 content. On the other hand, the effect on the K_2O extracted from the several mixtures is comparatively small, and consequently its estimation was not undertaken in the experiments which follow.

[1] *Mem. Dept. Agri., India, Chem. Series*, Vol. V, 1921, 203

II. Extraction with a saturated solution of calcium citrate.

Table II.

Showing the extraction of P_2O_5 from Kalianpur soil with a saturated solution of calcium citrate and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
	A. *Kalianpur soil + $CaCO_3$*		
100	nil	0·00032	
95	5	0·00027	0·00030
90	10	0·00025	0·00029
85	15	0·00030	0·00027
80	20	0·00026	0·00026
75	25	0·00019	0·00024
70	30	0·00017	0.00022
	B. *Kalianpur soil + Pusa soil*		
	Grm. Pusa soil added		
100	nil	0·00032	
95	5	0·00033	0·00032
90	10	0·00030	0·00032
80	20	0·00025	0·00031
70	30	0·00019	0·00031
60	40	0.00017	0·00030
nil	100	0·00028	0·00028

All the extracts were colourless, showing the absence of organic matter from the solution. The effect of either $CaCO_3$ as such or in the form of Pusa soil on the extraction of P_2O_5 appears much less than in the case of 1 per cent. neutral ammonium citrate solution. It is to be noted, however, that the amount of P_2O_5 extracted from every soil mixture is so small as to give rise to great manipulative difficulties in its estimation by the standard ammonium molybdate method, and, therefore, likely to introduce large experimental errors. Consequently, it would not be desirable to draw any conclusion from such data unless a more reliable method for the estimation of P_2O_5 in minute quantities is available.

III. Extraction with a saturated solution of calcium citrate and calicum bicarbonate.

Table III.

Showing the extraction of P_2O_5 from Kalianpur soil with a saturated solution of calcium citrate and calcium bicarbonate and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
	A. *Kalianpur soil + $CaCO_3$*		
100	nil	0·00122	
95	5	0·00039	0·00116
90	10	0·00039	0·00110
85	15	0·00028	0·00104
80	20	0·00024	0·00098
75	25	0·00026	0·00092
70	30	0·00024	0·00086
	B. *Kalianpur soil + Pusa soil*		
	Grm. Pusa soil added		
100	nil	0·00122	—
95	5	0·00056	0·00118
90	10	0·00045	0·00114
80	20	0·00034	0·00107
70	30	0·00024	0·00099
60	40	0·00019	0·00092
nil	100	0·00046	0·00046

All the extracts were colourless, showing the absence of organic matter from the solution. It is evident that the presence of both $CaCO_3$ and Pusa soil has depressed the solubility of the soil phosphates, but the effect of Pusa soil is more pronounced than that of $CaCO_3$ as shown in the case of 1 per cent. neutral ammonium citrate solution.

IV. Extraction with 1 per cent. Na_2SO_4 solution (about N/7 strength).

Table IV.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. Na_2SO_4 solution and the effect of $CaCO_3$ on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
100	nil	0·0014	.
95	5	0·0012	0·00133
90	10	0·0011	0·00126
85	15	0·0008	0·00119
80	20	0·0007	0·00105
75	25	0·0006	0·00105

As the extraction of Pusa soil with 1 per cent. Na_2SO_4 solution gave only 0·00032 per cent. P_2O_5, the study of its action was not considered necessary.

All the extracts were colourless. The amount of P_2O_5 extracted in some of the mixtures is so small as to have no practical value. The addition of $CaCO_3$ has, however, interfered with the extraction of P_2O_5 to a certain extent.

V. Extraction with 1 per cent. $(NH_4)_2SO_4$ solution (about N/7 strength).

When the $(NH_4)_2SO_4$ solution, which gives acid reaction owing to hydrolysis, is shaken with $CaCO_3$, the resultant solution is alkaline to litmus owing probably to the production of $(NH_4)_2CO_3$ according to the following equation

$$(NH_4)_2SO_4 + CaCO_3 = CaSO_4 + (NH_4)_2CO_3.$$

The experimental results of the extraction of P_2O_5 are given in the following table.

Table V.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. $(NH_4)_2SO_4$ solution and the effect of $CaCO_3$ on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
100	nil	0·0015	-
95	5	0·0009	0·00143
90	10	0·0008	0·00135
85	15	0·0006	0·00128
80	20	0·0004	0·00120
75	25	0·0006	0·00113

The extracts were all colourless and slightly alkaline in reaction. The effect of $CaCO_3$ on the amount of P_2O_5 extracted is very pronounced.

VI. Extraction with 1 per cent. $(NH_4)_2CO_3$ solution (about N/5 strength).

Table VI.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. $(NH_4)_2CO_3$ solution and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
	A. *Kalianpur soil + $CaCO_3$*		
100	nil	0·0032	
95	5	0·0050	0·00304
90	10	0·0057	0·00288
85	15	0·0062	0.00272
80	20	0·0063	0·00256
75	25	0·0064	0·00240
	B. *Kalianpur soil + Pusa soil* Grm. Pusa soil added		
100	nil	0·0032	
95	5	0·0035	0·00308
90	10	0·0035	0·00296
80	20	0·0032	0·00273
70	30	0·0029	0·00249
60	40	0·0026	0·00226
nil	100	0·00084	0·00084

The extracts were all brownish, showing the presence of a considerable amount of humus in the solution. As the humus contains an appreciable proportion of P_2O_5, he results obtained are very interesting. The presence of $CaCO_3$ here does not educe the amount of P_2O_5 extracted as in the previous cases. On the other hand, not being affected by the $(NH_4)_2CO_3$ solution it becomes an inert substance directly ncreasing the ratio of the solvent to the soil. Thus, with increasing amounts $CaCO_3$ n the soil mixtures, the solvent extracts more and more humus and consequently ncreasing proportions of P_2O_5, which is made evident from the results obtained.

On the other hand, the presence of Pusa soil does not appear to affect the extraction of P_2O_5 appreciably, as it consists not only of $CaCO_3$ as in the former case, but also other constituents of soil which are evidently acted on by the $(NH_4)_2CO_3$ solvent. The latter, being alkaline in reaction, is capable of extracting humus from Pusa soil as will be shown later on and it is well known that humus retains P_2O_5 with it. For

the present, however, it may be taken that all these phenomena play an important rôle on the results obtained and do not exert a depressing influence on the amount of P_2O_5 extracted. Thus, Pusa soil present in these soil mixtures being itself acted upon by the solvent employed cannot contribute towards incremental extraction of humus and P_2O_5 as the presence of pure $CaCO_3$ did in the case of its mixtures with Kalianpur soil.

Lastly, a few experiments were carried out in order to determine the amount of humus extracted from the soils used in this investigation, and also the proportion of P_2O_5 present in the same.

Ten or twenty grammes of each soil were treated directly with 500 c.c. of 4 per cent. ammonia solution in the cold and allowed to stand overnight. Then in an aliquot portion of the supernatant liquid humus was determined and in another portion P_2O_5 estimated in the usual manner. The results are shown in the following table.

TABLE VII.

Showing the amounts of humus and P_2O_5 in the humus extracted from Kalianpur and Pusa soils with 4 per cent. ammonia solution.

Substance	Per cent. humus	Grm. P_2O_5 in per cent. humus	Per cent. P_2O_5 in humus
Kalianpur soil	0·23	0·0115	5·00
Pusa soil	0·38	0·0022	0·58

Pusa soil contains 65 per cent. more humus than Kalianpur soil, but the humus of the latter is about 9 times richer in P_2O_5 content than that of the former.

Thus, although the presence of $CaCO_3$ does not directly interfere with the extraction of P_2O_5 by 1 per cent. $(NH_4)_2CO_3$ solution, it indirectly affects the extraction of P_2O_5 favourably as shown above. A similar effect, however, cannot be expected from the mixture with Pusa soil which takes part in the reaction involved, and this has been found to be the case as shown in Table VI (B) above.

In conclusion, it is believed that some alkaline solvent, while extracting appreciable amounts of P_2O_5 and at the same time not being appreciably affected by the presence of $CaCO_3$, will be found suitable for the estimation of available P_2O_5 in calcareous soils. This investigation will be dealt with in Part III of this Memoir.

SUMMARY.

With a view to find out a suitable solvent for the estimation of available phosphoric acid in calcareous soils, several salt solutions, such as, 1 per cent. neutral

ammonium citrate, saturated solution of calcium citrate, saturated solution of calcium citrate and calcium bicarbonate together, 1 per cent. Na_2SO_4, 1 per cent. $(NH_4)_2SO_4$ and 1 per cent. $(NH_4)_2CO_3$ solutions were employed in the extraction of a non-calcareous Kalianpur soil mixed with varying proportions of $CaCO_3$ and the calcareous Pusa soil. It was found that in most cases the presence of $CaCO_3$ in any form reduced the amount of P_2O_5 extracted. An exception was noticed in the case of 1 per cent. $(NH_4)_2CO_3$ solution when the effect of the $CaCO_3$ was an indirect one in that its increasing proportion in the soil mixtures increased the proportion of the solvent to the soil, and, consequently, the solvent, which is alkaline in reaction, extracted more and more humus and increasing amounts of P_2O_5 from the soil mixtures.

It was thought probable that some alkaline solvent, while extracting appreciable amounts of P_2O_5, would be found suitable for the estimation of available P_2O_5 in calcareous soils, as increasing proportions of $CaCO_3$ did not lead to a reduction in the amount of P_2O_5 extracted.

PART III.

Potassium Carbonate Method for Estimation of Available Phosphoric Acid of Highly Calcareous Soils.

It has been demonstrated in the earlier portions of this Memoir that the employment of acid solvents is inapplicable to the estimation of available phosphoric acid in calcareous soils and that calcium carbonate exerts a depressing influence on extraction by solutions of a number of salts. The investigations, however, indicated the possibility that some alkaline solvent would extract appreciable amounts of phosphoric acid which probably would be found of value in giving some criterion for the differentiation of the manurial requirements of soils of this type.

Ammonium hydroxide solutions extract humus and the phosphoric acid combined with it, from soils, and Olson[1] has shown that such solutions can be employed to differentiate between the mono-, di-, and tri-calcium phosphates not only in the presence of each other, but also as they exist in fertilizers, animal and plant tissues, soils, etc. In a previous paper,[2] the author has shown that in calcareous soils there is a very rapid reversion of mono- into di-calcic phosphate and that the latter only very slowly reverts into the tri-calcic form. On this basis, therefore, there would appear to be a possibility of employing ammonia solutions for the manurial differentiation of such soils, and a number of preliminary experiments were instituted to test this point.

In the first instance it was thought desirable to see whether or not varying proportions of soil to a fixed volume of solvent had any effect on the percentage of P_2O_5 extracted. Quantities of Kalianpur soil varying from 20 to 100 grm. were therefore extracted with 500 c.c. of 4 per cent. ammonia solution in the cold by shaking together for two hours and then allowing the mixture to stand overnight. The clear solution was separated by suction through a filter and the dissolved P_2O_5 estimated in the usual manner. The results are set forth in the following table.

TABLE I.

Showing the results of P_2O_5 extractions from varying amounts of Kalianpur soil with a constant volume of 4 per cent. ammonia solution.

Grm. Kalianpur soil taken	Volume of 4 per cent. ammonia solution added	Per cent. P_2O_5 extracted
20	500 c.c.	0·00098
30	,,	0·00098
40	,,	0·00098
50	,,	0·00118
100	,,	0·00101

[1] *Washington Agri. Exp. Sta. Bull.* 116, 1914.
[2] Harrison and Das. *Mem. Dept. Agri. India, Chem. Ser.*, Vol. V, No. 9, 1921.

Thus it is shown that, under very wide variations between the weight of soil taken and the volume of solvent used, the percentage of P_2O_5 extracted remains practically constant.

The next step was to determine the effect of the presence of calcium carbonate or Pusa soil on the amount of P_2O_5 extracted from mixtures. Mixtures of varying composition were made and extracted for six hours in a shaking machine with a 4 per cent. ammonia solution. After standing overnight the solution was separated by filtration and the P_2O_5 in it estimated. The results are given in the following table.

Table II.

Showing the effect of precipitated $CaCO_3$ on the extraction of P_2O_5 from Kalianpur soil with 4 per cent. ammonia solution.

Per cent. $CaCO_3$ in soil mixture	Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 extractable in soil mixture (*calculated*)	Grm. P_2O_5 extracted in soil mixture (*found*)	Difference
nil	300	nil	—	0·00229	—
5	285	15	0·00216	0·00144	—0·00072
10	270	30	0·00205	0·00124	—0·00081
20	240	60	0·00182	0·00083	—0·00099
30	210	90	0·00160	0·00056	—0·00104
40	180	120	0·00137	0·00039	—0·00098
80	60	240	0·00046	0·00016	—0·00030
100	nil	200	nil	nil	—

Table III.

Showing the effect of Pusa soil on the extraction of P_2O_5 from Kalianpur soil with 4 per cent. ammonia solution.

Per cent. Pusa soil in soil mixture	Grm. Kalianpur soil taken	Grm. Pusa soil added	Grm. P_2O_5 extractable in soil mixture (*calculated*)	Grm. P_2O_5 extracted in soil mixture (*found*)	Difference
nil	300	nil	—	0·00229	—
20	240	60	0·00209	0·00201	—0·00008
40	180	120	0·00191	0·00167	—0·00024
60	120	180	0·00172	0·00159	—0·00013
80	60	240	0·00154	0·00142	—0·00012
100	nil	300	0·00135	0·00135	—

These results show distinctly that the presence of $CaCO_3$ decreases the amount of P_2O_5 which is extracted from its mixture, but that this effect is comparatively small in mixtures with Pusa soil. This difference possibly may be due to the particles of $CaCO_3$ in the Pusa soil being partially protected by other soil constituents, and if this is the case, then by extracting increasing proportions of Pusa soil with the same volume of 4 per cent. ammonia solution and thus increasing the amounts of active $CaCO_3$ present, the percentage of P_2O_5 extracted should show a depression. Experiments on these lines were instituted and the results are given in the following table.

TABLE IV.

Showing the results of P_2O_5 extractions from varying amounts of Pusa soil with a constant volume of 4 per cent. ammonia solution.

Ratio of grm. Pusa soil : 500 c.c. 4 per cent. ammonia solution	Grm. Pusa soil actually taken	c. c. 4 per cent. ammonia solution actually used	Per cent. P_2O_5 extracted
20	120	3,000	0·00075
30	135	2,250	0·00067
40	180	2,250	0·00056
60	180	1,500	0·00053
80	240	1,500	0·00050
100	300	1,500	0·00045

It is evident that there is a decrease in the proportion of P_2O_5 extracted as the proportion of soil increases, a result diametrically opposed to that obtained from the Kalianpur soil, and it may be concluded that ammonia extraction is susceptible to the influence of $CaCO_3$ and therefore inapplicable to calcareous soils.

A reference to the experiments detailed in Part II shows that the presence of $CaCO_3$ had comparatively little effect on the P_2O_5 extracted by a 1 per cent. ammonium carbonate solution. It seemed desirable to use a stronger solution of ammonium carbonate and to compare its action with those of sodium and potassium carbonates. The results are given in the following table, the amount of soil and the volume of alkaline carbonate solution taken being 300 grm. and 1500 c.c. respectively.

TABLE V.

Showing the results of P_2O_5 extractions from Kalianpur and Pusa soils with approximately N/2 alkaline carbonate solutions.

N/2 solution used	Per cent. P_2O_5 from Kalianpur soil	Per cent. P_2O_5 from Pusa soil
2·85 per cent. $(NH_4)_2CO_3$	0·00458	0·00143
2·65 per cent. Na_2CO_3	0·00428	0·00249
3·45 per cent. K_2CO_3	0·00473	0·00271

It is found that in the case of the Kalianpur soil which is practically devoid of lime, the amounts of P_2O_5 extracted are practically the same with the three solvents tried, whereas in the case of the highly calcareous Pusa soil the amount of P_2O_5 extracted by the $(NH_4)_2CO_3$ solution is about half of what has been obtained by the rest of the solvents. The reason of this probably lies in the fact that $(NH_4)_2CO_3$ is a much weaker base than the other two and is unstable, especially in the presence of $CaCO_3$ which is a constituent of the soil itself. Further attempts with this solvent were therefore not made. Of the other two solvents, K_2CO_3 extracted a little more P_2O_5 both from Kalianpur and Pusa soils than Na_2CO_3. Potassium carbonate was therefore selected for further investigation, and extractions of Pusa soil with solutions of various strengths over different periods of time were carried out. 75 grm. of soil and 750 c.c. of the solvent were used in the following experiments and the results are set forth in the following table.

TABLE VI.

Showing the results of P_2O_5 extractions from Pusa soil with K_2CO_3 solution of various strengths over different periods of time.

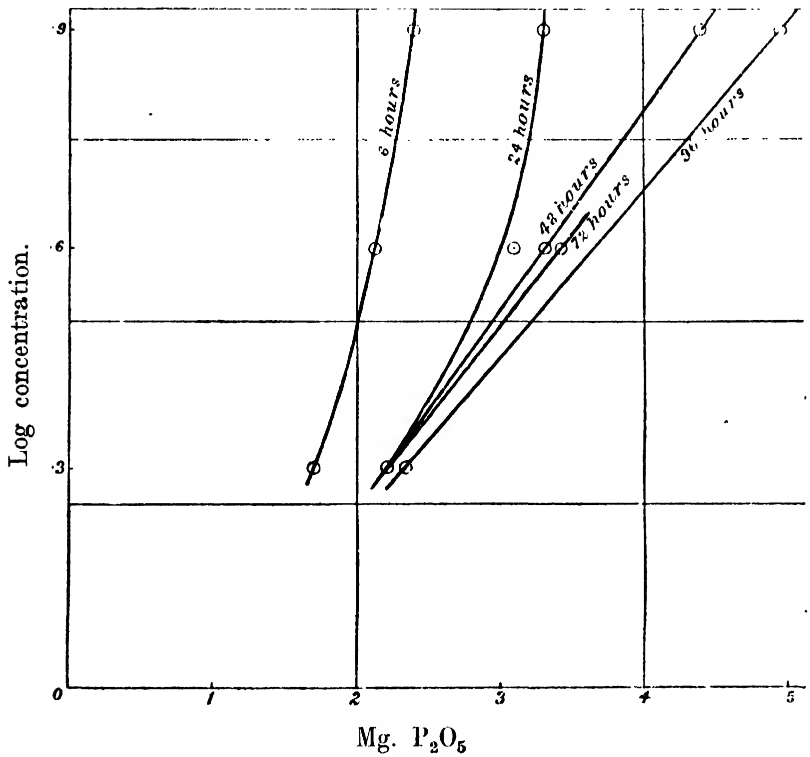
Time of shaking in hours	With ½ per cent. K_2CO_3 solution	With 1 per cent. K_2CO_3 solution	With 2 per cent. K_2CO_3 solution
	Per cent. P_2O_5 extracted	Per cent. P_2O_5 extracted	Per cent. P_2O_5 extracted
6	0·00170	0·00214	0·00239
8	—	0·00221	—
24	0·00221	0·00309	0·00328
48	0·00221	0·00334	0·00441
72	0·00221	0·00340	—
96	0·00233	—	0·00498
120	—	0·00359	—

It is evident that the greater the concentration of K_2CO_3 solution used, the larger were the quantities of P_2O_5 extracted, and that the effect of time on the extraction of P_2O_5 is not much pronounced beyond 24 hours' shaking except in the case of 2 per cent. K_2CO_3 solution. On the other hand, the variation in the proportions of P_2O_5 extracted on 24 hours' shaking is much less pronounced than on longer periods of shaking. Further, 1 per cent. K_2CO_3 solution is capable of extracting an appreciable amount of P_2O_5 with 24 hours' shaking and this amount remains practically constant with longer times of shaking. Shaking with 1 per cent. K_2CO_3 solvent for 24 hours was therefore fixed as a standard method of procedure for the estimation of available phosphoric acid in calcareous soils. The fixing of the above standards is further confirmed by the following considerations.

The relationship between the amounts of P_2O_5 (P) extracted on shaking different lengths of time and the corresponding concentration (C) of K_2CO_3 solutions used turns out to be a simple semi-logarithmic one, as is shown by plotting the values of P against log C, when the curves produced are approximately straight lines. The following diagram demonstrates this, where concentrations are taken as 2, 4 and 8 respectively in the place of $\frac{1}{2}$, 1 and 2 per cent. K_2CO_3 for the sake of drawing the curves.

DIAGRAM I.

Showing the curves produced on plotting milligrams P_2O_5 extracted from Pusa soil against the logarithms of corresponding concentrations of K_2CO_3 solutions.



The relationship may thus be expressed by the general formula –

$P = a + b \log C$,

where P = mg. P_2O_5 extracted,

C = concentration of K_2CO_3 solution used,

and a and b are constants.

That is to say, the extraction of P_2O_5 from Pusa soil follows the law of mass action, the proportion of P_2O_5 extracted at any time being a function of the total

amount of P_2O_5 and depending upon the concentration of K_2CO_3 solution used. It is also evident from the curve that there is less variation in the amounts of P_2O_5 extracted with 24 hours' shaking, which has been adopted as the standard.

To find out the theoretical considerations underlying the action of K_2CO_3 solvent on the phosphates of calcareous soils, some experiments were next undertaken.

Extracting a sample of dicalcic phosphate with 1 per cent. K_2CO_3 solution *in the cold* yielded results which are set forth in the following table.

TABLE VII.

Showing the results of P_2O_5 extractions from dicalcic phosphate on being shaken for different periods of time.

Time of shaking in hours	Grm. dicalcic phosphate taken	1 per cent. K_2CO_3 solution added	Grm. P_2O_5 in solution after shaking	Per cent action
24	0·5	100 c. c.	0·0318	46·7 } mean = 49·6
24	1·0	,,	0·0697	50·7
24	2·0	,,	0·1411	51·4
48	1·0	,,	0·0939	68·2
96	1·0	,,	0·1292	93·9

The reaction between dicalcic phosphate and K_2CO_3 solution is thus seen to be a progressive one depending upon the time of shaking, the extraction evidently proceeding to completion after a little longer time than 96 hours. The reaction which takes place is shown by the following equation :—

$3\ CaHPO_4,\ 2\ H_2O + K_2CO_3 = Ca_3\ (PO_4)_2 + K_2HPO_4 + CO_2 + 7\ H_2O.$

$3 \times 172 = 516$. Potassium Tricalcium Potassium

Dicalcic phosphate. carbonate. phosphate. phosphate.

(P_2O_5 in solution=71).

From this it follows that 1 grm. of dicalcic phosphate will leave in solution 0·1376 grm. of P_2O_5 from potassium phosphate produced when the reaction is complete.

The above table also shows that 94 per cent. action took place according to the above relation *in the cold* on 96 hours' shaking. It was therefore thought possible that the velocity of reaction will be quicker *in a boiling solution* and the reaction will be complete within a shorter space of time.

To test this, 0·7408 grm. of dicalcic phosphate was boiled with 70 c.c. of 1 per cent. K_2CO_3 solution for about ten minutes. Then, after separating the extract by filtration, the dissolved P_2O_5 was determined as usual. The results are shown below.

P_2O_5 *found* in solution = 0·1014 grm.
,, *calculated* ,, = 0·1019 ,,

Difference = — 0·0005 ,,

Thus, the reaction between dicalcic phosphate and 1 per cent. K_2CO_3 solution takes place according to the equation given above, whether in the cold or in a boiling solution.

Evidently, the underlying principle of the action of 1 per cent. K_2CO_3 solvent on calcareous soils seems to be that a reaction takes place with any dicalcic or such other phosphates present in the soils in the production of insoluble tricalcium or other phosphates, and of soluble potassium phosphate. The amount of P_2O_5 found in the extract thus serves to be an approximate measure of the available phosphoric acid of calcareous soils.

To find out the suitable ratio of soil to the solvent used in the extractions of P_2O_5, a definite amount of soil was extracted with varying proportions of the solvent. In this case, the soil mixtures were shaken for six hours only and then the whole allowed to stand overnight, after which the extracts were examined for the dissolved P_2O_5 as usual. The results are shown in the following table.

TABLE VIII.

Showing the results of P_2O_5 extractions from Pusa soil with varying amounts of 1 per cent. K_2CO_3 solution.

Ratio of grm. soil : c. c. solvent	Grm. Pusa soil actually taken	c.c. 1 per cent. K_2CO_3 solution actually added	Per cent. P_2O_5 extracted
1 : 5	300	1,500	0·00186
1 : 10	150	1,500	0·00290
1 : 15	50	750	0·00255

It is thus demonstrated that when the soil and the solvent were taken in the ratio of 1 : 10, the maximum amount of P_2O_5 was extracted under the conditions of the experiment. This ratio was therefore taken as the suitable standard, and has since been adopted in all subsequent experiments.

It was found by experience that slight variations of temperature did not materially affect the results obtained.

The following method for the estimation of available phosphoric acid of calcareous soils is therefore recommended :—

" The soil is sampled by passing through a sieve of 2 mm. meshes after drying it in the air ; 100 grm. of it with a litre of 1 per cent. K_2CO_3 solution, or a similar proportion of the soil and the solvent, should be shaken in the cold for 24 hours in end-over-end rotations in a mechanical shaker in a room which is not subjected to sudden changes of temperature. In the extract separated by suction, the P_2O_5 is determined by the ammonium molybdate method."

A precaution has, however, to be taken during the analysis that the K_2CO_3 remaining free in the extract should be first neutralized almost wholly with nitric acid and then with a little hydrochloric acid, as a result of which considerable amounts of potassium nitrate will be produced in the solution, which is an advantage in the granular precipitation of ammonium phosphomolybdate during subsequent operations. Otherwise, if hydrochloric acid is used instead for neutralization in the beginning, the excess of chloride produced will, as is well known, materially interfere with the estimation of P_2O_5 by the molybdate method[1].

In order to verify this method as well as to compare its advantages over the existing citric acid method, a large number of calcareous soils from Pusa experimental plots, of $CaCO_3$ content ranging from 30 to 40 per cent., was taken for examination, the cropping and manurial history of these soils being accurately known.

The total P_2O_5 content of these soils did not vary to a considerable extent and the figures for available P_2O_5 determined by the citric acid method, which were almost uniformly lower than 0·0005 per cent., were rather erratic. On the other hand, the amounts extracted by 1 per cent. K_2CO_3 solution, which gave a wider variation from about 0·002 to 0·005 per cent. P_2O_5, showed indication of being significantly related to the cultural history of the plots. The results obtained are given in the following table.

TABLE IX.

Showing the comparable results of total P_2O_5 by citric acid as well as potassium carbonate methods, of calcareous soils of known cropping and manurial history.

Plot No.	Description of plots	Treatment	Per cent. total P_2O_5	Per cent. available P_2O_5		Ratio $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$
				By citric acid method	By potassium carbonate method	
1 B.	Punjab Field	No manure	0·1082	0·00029	0·00227	0·021
8 B.	,,	Superphosphate	0·1051	0·00029	0·00290	0·028
7 B.	,,	K_2SO_4	0·1033	0·00022	0·00233	0·023
9 B.	,,	,, + Super	0·1031	0·00019	0·00328	0·032
19 D.	,,	Green manure + Gypsum.	0·0966	0·00011	0·00239	0·025
15 D.	,,	,, + Monocalcic phosphate.	0·0959	0·00009	0·00277	0·029

[1] Hibbard, P. L. A study of the Pemberton-Kilgore Method for the determination of phosphoric acid. *Jour. Indus. and Engin. Chem.*, 5. Dec. 1913, 998.

TABLE IX—*concld.*

Plot No.	Description of plots	Treatment	Per cent. total P_2O_5	Per cent. available P_2O_5 By citric acid method	Per cent. available P_2O_5 By potassium carbonate method	Ratio $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$
1 . .	North Pangarbi Field.	No manure .	0·1023	0·00006	0·00309	0·030
3 . .	,, . .	Superphosphate .	0·1051	0·00016	0·00479	0·045
2 . .	,, . .	Green manure .	0·1023	0·00006	0·00271	0·026
4 . .	,, . .	,, + Super	0·1021	0·00006	0·00391	0·038
1 . .	Pot Culture House Field.	No manure .	0·1071	0·00028	0·00392	0·035
8 . .	,, . .	Superphosphate .	0·1110	0·00107	0·00435	0·039
7 . .	,, . .	$(NH_4)_2SO_4$.	0·0941	0·00020	0·00353	0·038
4 . .	,, . .	,, + Super .	0·1065	0·00020	0·00410	0·039
9 . .	,, . .	K_2SO_4 . .	0·0972	0·00011	0·00397	0·041
6 . .	,, . .	,, + Super .	0·1111	0·00095	0·00536	0·048

In another case, a plot No. 30 B in the Punjab Field, which had received a dressing of super several years ago and none since, gave 0·00378 per cent. P_2O_5 by K_2CO_3 extraction, the corresponding no manure plot No. 27 B giving only 0·00258 per cent. against 0·00013 per cent. and 0·00052 per cent. available P_2O_5 respectively by the citric acid method from these plots. More recently, a supered plot in the Chhoania Field gave 0·00517 per cent. P_2O_5 as against 0·00277 per cent. P_2O_5 by K_2CO_3 extraction for an unmanured plot in the same field.

Thus, in practically all cases examined, the method of extracting with 1 per cent. K_2CO_3 solvent has differentiated between manured and unmanured plots, and also between plots treated with phosphatic fertilizers and those treated with other fertilizers having no phosphates in them, whereas the citric acid method yields uneven and misleading values.

In order to see whether this new method can differentiate between patches of soil carrying an uneven growth of a crop in the same field, an examination was made of calcareous soils taken from a field showing very irregular growth in the crop, samples being taken from good portions for comparison with samples from bad portions. The results are set forth in the following table.

TABLE X.

Showing comparable results of total P_2O_5 and available P_2O_5 by citric acid as well as by potassium carbonate methods of calcareous soils from good and bad cropping.

Description of plots	Per cent. total P_2O_5	Per cent. available P_2O_5		Ratio $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$
		By citric acid method	By potassium carbonate method	
Good cropping soil, No 1	0·1004	0·00038	0·00340	0·034
,, ,, ,, ,, 2	0·1014	0·00017	0·00296	0·029
,, ,, ,, ,, 3	0·1023	0·00016	0·00328	0·032
,, ,, ,, ,, 4	0·0979	0·00016	0·00334	0·034
Bad cropping soil, No 1	0·0981	0·00038	0·00365	0·037
,, ,, ,, ,, 2	0·1014	0·00032	0·00246	0·025
,, ,, ,, ,, 3	0·0972	0·00022	0·00239	0·025
,, ,, ,, ,, 4	0·0936	0·00022	0·00208	0·022

Thus, in three cases out of four, the good soils yielded appreciably higher values than the bad soils when examined by the K_2CO_3 extraction process, whereas with the citric acid method the reverse was the case.

Moreover, the ratios $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$ in the above two tables indicate that the K_2CO_3 solvent extracts appreciable quantities of P_2O_5 giving rise to no manipulative difficulties in their estimation which are very often met with in the case of small amounts of P_2O_5 extracted by the citric acid method. It is also evident that the proportions of P_2O_5 extracted with K_2CO_3 solution are many times greater than those obtained with the Dyer's method. As a matter of fact, the K_2CO_3 solution, being an alkaline solvent, extracts humus from soils, with which is associated a comparatively large amount of P_2O_5, whereas citric acid is incapable of doing so. It has already been shown to be the case in Part II (*loc. cit.*) that an alkaline solvent can extract humus and P_2O_5 combined with it from soils[1]. Thus, the greater solvent power of K_2CO_3 solution for soil phosphates is clearly demonstrated.

Furthermore, preliminary experiments carried out by the author in this laboratory[2] have shown that phosphorus in organic combination is more efficacious and easily available to plants than inorganic phosphorus in soils. Thus, it may perhaps be maintained that K_2CO_3 solution, which extracts phosphorus both in organic and

[1] Table VII, Part II.
[2] *Sci. Rept., Agri. Res. Inst., Pusa, India,* 1923-24, 24-25.

inorganic combinations in soils, is a very suitable solvent for estimating soil phosphates, which will be available for the nutrition of plants.

The conclusion thus emerges that the potassium carbonate method is capable of measuring the probable fertility of highly calcareous soils in their relation to available phosphoric acid. Moreover, it is a decided improvement on the existing citric acid method in that it has the following advantages over the latter.

1. The potassium carbonate method is capable of giving an indication of the probable fertility of calcareous soils in their relation to available phosphoric acid, whereas the citric acid method altogether fails as a discriminating agent in such soils.
2. The potassium carbonate solution is not materially affected by the presence of calcium carbonate.
3. It extracts higher proportions of P_2O_5 from calcareous soils in both organic and inorganic combinations, which are easily estimable by the ammonium molybdate method, whereas citric acid solution extracts in the majority of cases very small amounts of P_2O_5 giving rise to great manipulative difficulties in their estimation.
4. The potassium carbonate extraction is not practically affected by the time of shaking, whereas in the citric acid method a reference to the experiments detailed in Part I (*loc. cit.*) will show that the amount of P_2O_5 extracted is considerably depressed by a longer time of shaking.
5. The reaction of the potassium carbonate solution with the soil phosphates follows a simpler course, being controlled by the law of mass action.

Further investigation is in progress to see if this new method can be applied to other types of soils with similar advantage.

Summary and Conclusions.

1. Ammonium hydroxide, being affected by the presence of calcium carbonate, extracts very small quantities of P_2O_5 from calcareous soils and cannot therefore be applied for measuring their fertility. Othe1 alkalis are likely to behave in a similar way, and they were therefore not tried.

2. A solution of ammonium carbonate, although not affected by the presence of calcium carbonate, extracts smaller proportions of P_2O_5 from calcareous soils than do those of the other common alkali carbonates, even when strong solutions of approximately half-normal strengths are used.

3. Of Na_2CO_3 and K_2CO_3, the latter extracts more P_2O_5, and was therefore selected for the investigation.

4. It has been proved that 1 per cent. K_2CO_3 solution is capable of differentiating between manured and unmanured plots of known cropping and manurial history, and it thus gives an indication of the probable fertility of calcareous soils in their relation to available phosphoric acid.

5. An improved method has been recommended as a substitute for the existing Dyer's method for the estimation of available phosphoric acid of a highly calcareous soil in that the soil should be extracted with a 1 per cent. K_2CO_3 solution, the proportion of the soil to solvent being as 1: 10, on being shaken for 24 hours at the ordinary laboratory temperature and then the dissolved P_2O_5 in the extract estimated by the ammonium molybdate method.

On the other hand, the citric acid method altogether fails as a discriminating agent in such soils.

6. The reaction between 1 per cent. K_2CO_3 solution and the phosphates of calcareous soils obeys the law of mass action.

7. It has been established that the underlying principle of the action of 1 per cent. K_2CO_3 solution on calcareous soils is that (*a*) a reaction takes place with any dicalcic or such other phosphates present in the soils in the production of insoluble tricalcium or other phosphates, and of soluble potassium phosphate, and that (*b*) phosphorus in organic combination present in the humus of the soils is also dissolved.

8. The potassium carbonate method is a reliable one, and it has several advantages over the existing Dyer's citric acid method for estimating the available phosphoric acid when applied to highly calcareous soils.

Experiments are in progress to see if this new method can be successfully applied to other types of soils.

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BY

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CONTENTS

FOREWORD.

The work described in the following Memoir has been carried out during the past two years. The Senior Author is leaving India and will be unable to continue in charge of the investigations. It is, therefore, considered advisable to publish the results so far obtained. The work will, however, be continued by the joint authors of the paper.

H. E. ANNETT,

Agricultural Chemist to Government,
Central Provinces, Nagpur.

LOSSES AND GAINS OF NITROGEN IN AN INDIAN SOIL STUDIED IN RELATION TO SEASONAL COMPOSITION OF WELL WATERS, AND THE BEARINGS OF THE RESULTS ON THE ALLEGED DETERIORATION OF SOIL FERTILITY.

BY

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(Received for publication on 2nd September 1927.)

Much work has been carried out on nitrification and nitrogen fixation in soils in various countries. Most of the work on nitrification deals with the conditions affecting the process and figures have been given showing the amount of nitrate in the soil at various depths throughout the year. What happens to this nitrate after formation has received much less attention. Most writers assume that what is not used by the plant passes away into the subsoil water. It is certainly widely stated that little denitrification takes place in soils. The work carried out in this laboratory shows that the loss of nitrate from soils is very great and in view of various other interesting observations arising out of the work no apology seems needed for adding to the already vast literature on the subject. Much of the work on nitrification has been carried out on soils, the formations underlying which allow the subsoil water to pass rapidly away into neighbouring rivers. In the area on which our work has been carried out, we have a fairly uniform heavy black clay—the black cotton soil of India—40 to 50′ in depth resting on trap rock. In the rains the water level in wells rises to about 3 feet from the surface and in the hot weather it falls to a distance of 19 feet from the surface. These conditions are typical of a very large tract of country in the Central Provinces of India though the water levels and depth of soil vary in different parts. There will of course be lateral movement of this under-ground water supply towards the big river beds. Since there are no

big rivers near the Nagpur Farm, the probability is that the lateral movement is exceedingly slow. It occurred to us, therefore, that a study of the nitrate content of wells, undertaken in connection with a study of the nitrate content of the soil itself at various periods throughout the year, should give interesting results. Our experiments fall naturally into 3 divisions.

I. A study of the nitrate content of the top 3 feet of soil of various plots at frequent intervals throughout the year. These experiments have been carried on from June 1925 to date, January 1927. With this was included a study of the total nitrogen content of the top one foot of soil.

II. A study of two wells throughout the year, one of which is used for irrigation and one of which is not used at all. Regular determinations of well levels, total solids, nitrates, carbonates and bicarbonates were made.

III. A study of the nitrate content of the drainage water from the drains laid under these plots.

For the convenience of the reader unacquainted with the soil and climate of the Central Provinces of India, the following particulars are given. They relate to the head-quarters station, Nagpur.

Temperature at Nagpur in 1926.

—	Months											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum	88·5	99·6	101·8	109·7	111·7	114·0	102·6	92·6	91·0	92·9	91·5	90·3
Minimum	49·3	47·0	58·2	65·9	69·0	78·6	72·3	73·0	72·0	56·1	49·2	43·8

Rainfall.

Normal	·58	·56	·46	·50	·69	8·76	13·48	10·66	7·85	2·09	·56	·46
Total for year . .	..	..	..	..	..	..	..	..	..	..	..	46·65

Mechanical analysis.

Clay	42·5
Fine silt	19·6
Silt	12·5
Fine sand	7·4
Coarse sand	10·2
Moisture	3·3
Loss on ignition	3·0
Calcium carbonate	1·6
	100·1

Chemical analysis.

Fe_2O_3	11·25
Al_2O_3	9·39
MnO	0·26
CaO	1·82
MgO	1·79
K_2O } Na_2O	0·45
P_2O_5	0·06
SO_3	*Nil*
CO_2	0·44
Insoluble silicates and sand	68·71
Organic matter and combined water*	5·83
Total	100·00

* Containing total nitrogen	0·050
Available P_2O_5	0·008
,, K_2O	0·041

PART I.

A STUDY OF THE NITRATE CONTENT OF THE TOP 3 FEET OF SOIL OF VARIOUS PLOTS AT FREQUENT INTERVALS THROUGHOUT THE YEAR.

After this study was started, it was found necessary to increase the scope of the experiment on two subsequent occasions and therefore the experiment must be separately described for each of these periods.

PERIOD (*a*). 21ST JUNE 1925– 8TH APRIL 1926.

During this period two plots only were taken under observation. Both of these had been regularly cropped for years past with cotton and *juar* (*sorghum vulgare*) in alternate years, except for an occasional crop of sann hemp (*Crotalaria juncea*) or *Tur* (*Cajanus indicus*). One of them has received no manure in the history of the farm, certainly not during the past 25 years, and the other has received regularly every year a dressing of 4 tons per acre of cattle dung and in addition is topdressed during the growing season with nitrate of soda at the rate of 65 lb. per acre. The plots run north and south and each measures $\frac{1}{5}$th acre in area. The yields on these two plots for the past 5 years have been :—

	Yield per acre lb.				
	1922	1923	1924	1925	1926
	Cotton	*Juar*	Sann hemp	Cotton	*Juar*
Unmanured	281¼	7,005	7,125	375	7,615
Manured	500	13,365	8,125	660	11,785

The yield of cotton refers to kapas, *i.e.*, seed and lint, whereas the *juar* yield refers to green fodder. The figure shown for sann hemp refers to weight of fibre.

The plots are under-drained with tile drains at a depth of $2\frac{1}{2}$ feet. The outfall is bricked and the drainage of each area can be collected separately.

Period (*b*). 16th April 1926—28th October 1926.

It was felt advisable to include an uncropped plot in the experiment. This was done from 16th April 1926. Between the 2 plots already under experiment was an exactly similar plot also under-drained which had received no manure for many years past. This was divided lengthwise into two sub-plots. Both these plots were left fallow. One remained unmanured and the other received a dressing of cattle manure on 16th June 1926 just before the rains. On this same date the manured plot which was to be cropped also had a similar dressing of cattle manure. The experiment, therefore, from now on included 4 plots.

1. Uncropped unmanured.
2. Uncropped manured.
3. Cropped unmanured.
4. Cropped manured.

Period (*c*). 1st November 1926 to date, January 1927.

It was decided at this date to study the effect of cultivation at the close of the rains on nitrate formation in the soil during the cold weather. The uncropped unmanured and uncropped manured plots were, therefore, again subdivided and one-half of each was cultivated as described later.

Unfortunately, the land had been left too long and was too dry for efficient cultivation. Fortunately, a neighbouring field which was uncropped during the rains had been regularly cultivated at the close of the rains. It had been unmanured for years and was apparently similar in every way to the plots already under experiment. It was decided to sample this plot regularly from 1st November 1926 onwards with the other plots. It was left uncropped and is called plot III in the tables. Therefore from 1st November 1926 the following plots were under experiment :

1. Uncropped unmanured uncultivated.
2. Uncropped manured uncultivated.
3. Cropped unmanured uncultivated.
4. Cropped manured uncultivated.
5. Uncropped unmanured cultivated.
6. Uncropped manured cultivated.
7. Plot III uncropped unmanured cultivated.

The crop (*juar*) was removed from 3 and 4 on 13th November 1926. No. 7 differs from 5 and 6 in that it received regular cultivation after the rains ceased as though in preparation for a cold weather crop, whereas Nos. 5 and 6 were left too late and in consequence became too dry for efficient cultivation. They were weeded on 29th October and broken up by a heavy plough on 29th October. They were *bakhared*[1] on the 31st October. Very large clods were left and these were broken down by hand on 5th November. A clod crusher was run over the land on 12th November, but even then the surface soil was simply a mass of large hard lumps.

Method of soil sampling.

Owing to its heavy nature the soil is a difficult one to sample, especially when it is drying out. We have found the only practicable way is to take the top and the second 6″ sample with an ordinary cylindrical boring tube with sharp edges. For the next two portions of 6″ each a large auger is employed and for the 5th and 6th portions of 6″ a smaller auger is used. It would be desirable to follow the changes in nitrate content to a greater depth than 3 feet, but we have so far found no convenient method of sampling black cotton soil to a greater depth than this. At each sampling 4 borings were taken in each plot and they were combined to form one set of samples corresponding to each 6″ depth of soil. The borings were always taken on a line drawn across the middle of the plots breadthwise and each subsequent line of samples was taken approximately 1 foot further south of the preceding line of samples. After about 6 months the line of sampling was shifted back to the original line and then sampling proceeded as before. Thus it will be seen that all samples were taken in a narrow rectangle running breadthwise across the plots and reaching approximately 10 or 12 feet lengthwise along the plots.

In order to get an idea of the experimental error, the four sub-samples were analysed separately in certain cases and the results of these analyses are given later (Table IV).

Method of analysis.

The samples were placed in airtight bottles in the field and removed to the laboratory as rapidly as possible. The samples were in each case rapidly mixed and broken down in the laboratory. 50 grm. were weighed off for moisture estimation and dried for 12 hours before weighment, a second weighment being taken after 3 hours' further drying.

Nitrates.

Nitrate was estimated by the phenoldisulphonic acid method. 100 grm. of the sample were placed in a wide mouthed bottle fitted with a rubber stopper and a small amount of gypsum together with 300 c.c. water was added. The stopper

[1] Bakhar- a bladed harrow.

was inserted and the bottle shaken until the sample was completely broken down. The disintegration of the lumps was assisted where necessary by rubbing down with a rubber pestle. The liquid was filtered through Whatman's No. 1 filter paper,[1] which does not absorb nitrate. A convenient volume of the filtrate usually 100 c.c., the actual volume depending on the nitrate concentration expected, was evaporated to dryness in a porcelain basin. 2 c.c. of phenoldisulphonic acid was added, the residue being thoroughly wetted with the reagent. The basin was then heated on the water bath for 3 minutes, after which the contents were washed into a measuring cylinder with water. 10 c.c. of strong ammonia was added and the volume made up to 100 c.c. with water. After shaking, the cylinder was allowed to stand for 5 minutes and the depth of colour was matched against standard yellow glasses in a Lovibond's tintometer--these glasses having been previously standardised against pure nitrate solutions. The phenoldisulphonic acid method of nitrate estimation has been frequently criticised, but our experience of it is that when carefully carried out, it gives results of sufficient accuracy for ordinary soil investigations. The number of determinations carried out in our work was so great as to preclude the use of a reduction method which involved either the subsequent volumetric measure of nitric oxide, or a distillation of ammonia.

Total nitrogen.

This was determined by the ordinary Kjeldahl method on 20 grm. of the soil, copper sulphate and potassium sulphate being added in the usual manner. Moist samples of soil were always used as it has been shown in this laboratory that air-dry samples of heavy black cotton soil do not yield up the whole of their nitrogen in the Kjeldahl process.* In certain published work on nitrogen fixation, it would appear that the original soil has been analysed for total nitrogen in the air-dry condition. Various portions were then weighed off and left for varying periods with added amounts of water. The total nitrogen in these moist samples was then estimated and the increase found was ascribed to nitrogen fixation, whereas it could be largely accounted for by the difference in nitrogen content found by analysing the soil in the dry and moist condition. Early experiments on nitrogen fixation carried out in our own laboratory have been discarded, because it was not realised at the time that air-dry soil does not yield the whole of its nitrogen in the Kjeldahl process.

Rainfall.

A careful record of the rainfall was maintained throughout the duration of the experiment. The figures are given in Table V and are also plotted on the charts.

[1] Gimingham has shown that certain brands of filter paper absorb nitrates. *Jour. Agri. Sci.*, Vol. XIII, pp. 60-62, 1923.

* Bal, D. V. *Jour. Agri. Sci.*, XV, pp. 451-459, 1925.

Drainage.

A note was kept of the dates on which the drains were running and analyses were regularly made of the nitrate content of the drainage water. These results will be referred to in Part III.

Cultural operations.

These are set out below.

In the season 1925 the crop on the plots was cotton. The plots were all fallow throughout the cold weather 1925-26. The crop on the cropped plots in 1926 was *juar* (*sorghum vulgare*).

1925.

——	Manured plot	Unmanured plot
June, 7th . . .	Spreading manure . . .	....
„ 8th . . .	Bakharing	Bakharing
„ 18th . . .	„	„
„ 19th . . .	Sowing	Sowing
July, 8th . . .	Hoeing	Hoeing
„ 15th . . .	Weeding	Weeding
August, 17th . . .	....	Hoeing
„ 20th . .	Top-dressing	....
„ 22nd . .	Hoeing	....
October, 27th . . .	Cotton picking	Cotton picking
November, 26th . .	„ „	„ „
December, 27th . .	„ „	„ „

1926.

Plot No.	1	2	3	4	5	6	7
March, 3rd . .	..	Disc ploughing by tractor			..	..	..
May, 27th . .	..	Bakharing by bullocks			..	..	..
June, 7th . .	..	Bakharing by tractor			..	..	..
„ 17th . .	Bakharing	Manuring and Bakharing	Bakharing	Manuring and Bakharing	Bakharing	Manuring and Bakharing	Bakharing
July, 6th . .	..	..	Bakharing by bullocks		..	..	..
„ 7th . .	..	..	Harrowing	..	..	..	..
„ 9th . .	..	..	Sowing	Sowing	..	..	..
„ 18th . .	..	..	..	..	..	..	Bakharing
Sep., 12th . .	..	..	..	..	..	..	Tractor Bakharing and Spring tooth cultivation
„ 24th . .	..	..	..	..	..	..	Ditto
Oct., 19th . .	..	..	..	..	..	..	Bakharing
„ 22nd . .	..	..	..	..	..	..	Harrowing
„ 28th . .	Weeding						..
„ 29th . .	..	..	..	..	Weeding and ploughing		..
„ 31st . .	..	..	..	..	Bakharing		..
Nov., 5th . .	..	..	..	..	Clods broken by hand		..
„ 12th . .	..	..	.	..	Clod crusher working		..
„ 13th . .	..	..	Harvesting fodder		..	..	..

The results obtained are set out in the following tables. Table I gives the results for the period (*a*) from 21st June 1925 to 6th April 1926. As already stated two plots only were under experiment during this period, one being manured and the other unmanured. The remarks column shows the dates of various cultural operations, manurial applications, date of sowing, height of crop at various dates, date of harvest, etc. The Table gives the water content of the soil at each sampling and also expresses the amount of nitrate in the soil. For convenience, this is expressed in 2 ways, firstly as grm. of nitrate of soda per 100 grm. dry soil and secondly as lb. of nitrate of soda per acre. For the purpose of the second method of expression an acre of dry soil 6″ deep has been assumed to weigh 1,500,000 lb,

Table I. Period (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925 —8th April 1926.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
21st June 1925	0–6″	34·0	·0034	51·21	34·6	·0043	64·3
	6–12″	20·0	·0019	27·91	17·7	·0014	21·78
	12–18″	21·4	·00094	14·14	20·7	·0019	28·09
	18–24″	23·3	·0011	17·31	22·0	·0017	25·63
	24–30″	26·1	·00	0·00	25·2	·0012	17·64
	30–36″	22·9	·00	0·00	25·9	·0012	17·79
				110·57			175·23
25th June 1925	0–6″	33·40	·0021	31·81	32·2	·0025	37·38
	6–12″	31·7	·0029	43·86	32·1	·0071	106·90
	12–18″	30·3	·0041	61·86	30·7	·0045	68·29
	18–24″	26·9	·0044	65·82	25·9	·0031	47·11
	24–30″	32·8	·0013	18·99	23·0	·0031	46·00
	30–36″	27·0	·0012	17·97	24·7	·0023	35·13
				240·31			340·81
1st July 1925	0–6″	36·6	·0017	26·22	36·5	·0017	26·17
	6–12″	34·8	·0021	32·22	35·7	·0022	32·49
	12–18″	34·1	·0043	64·06	33·9	·0064	95·89
	18–24″	32·4	·0046	69·39	33·1	·0021	31·71
	24–30″	29·8	·0016	24·63	30·1	·0029	43·20
	30–36″	28·8	·0016	24·39	28·9	·0045	67·12
				240·91			296·58
8th July 1925	0–6″	38·8	·0024	36·75	37·3	·0022	32·98
	6–12″	36·8	·0025	39·39	37·5	·0026	39·63
	12–18″	34·8	·0032	48·36	34·8	·0039	58·02
	18–24″	34·7	·0030	45·10	33·5	·0055	82·81
	24–30″	34·4	·0026	38·53	32·5	·0034	50·47
	30–36″	35·0	·0024	35·52	31·4	·0033	49·98
				243·65			313·89
15th July 1925	0–6″	38·6	·0013	20·01	39·5	·0018	26·89
	6–12″	37·4	·0013	19·78	36·1	·0017	26·10
	12–18″	36·4	·0013	19·62	34·8	·0013	19·35
	18–24″	36·1	·0013	19·57	35·3	·0022	32·37
	24–30″	35·4	·0013	19·45	35·1	·0021	32·32
	30–36″	36·4	·0022	32·71	35·8	·0022	32·53
				131·14			169·56

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925–8th April 1926—contd.

Date	Depth	UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
22nd July 1925	0–6″	37·3	·0031	46·15	38·6	·0027	40·02
	6–12″	36·0	·0015	22·83	36·2	·0017	26·13
	12–18″	35·0	·0017	25·83	33·7	·0021	31·90
	18–24″	35·5	·0022	32·44	34·8	·0021	32·23
	24–30″	35·5	·0019	29·19	36·5	·0048	72·06
	30–36″	34·6	·0021	32·17	36·3	·0054	81·67
				188·61			284·01
30th July 1925	0–6″	44·0	·00087	13·00	40·8	·00084	12·65
	6–12″	42·2	·0010	14·94	36·2	·00099	14·86
	12–18″	39·7	·00099	14·63	36·7	·00067	10·05
	18–24″	39·6	·00099	14·63	37·9	·00069	10·36
	24–30″	38·3	·00096	14·45	37·9	·0025	37·99
	30–36″	36·2	·00094	14·18	33·7	·0040	59·41
				85·83			145·32
3rd August 1925	0–6″	37·2	·0011	16·35	36·9	·00095	14·26
	6–12″	36·3	·00081	12·16	34·6	·00093	13·97
	12–18″	36·6	·00068	10·16	32·3	·0011	16·08
	18–24″	36·4	·00068	10·14	34·8	·0011	16·00
	24–30″	34·8	·00027	4·00	35·1	·00094	14·04
	30–36″	35·3	·0011	16·08	36·6	·0013	20·32
				68·89			94·67
13th August 1925	0–6″	39·1	·0017	24·94	38·0	·00082	12·35
	6–12″	38·4	·0014	20·67	35·3	·00080	12·06
	12–18″	35·8	·0013	20·17	34·8	·00093	14·00
	18–24″	37·4	·0014	20·49	34·5	·00080	11·95
	24–30″	37·8	·0018	26·97	37·3	·0012	18·42
	30–36″	38·9	·0018	27·24	36·5	·0012	18·27
				140·48			87·05
20th August 1925	0–6″	39·1	·00083	12·50	41·5	·0015	23·34
	6–12″	41·5	·00071	10·61	39·2	·00090	13·49
	12–18″	41·4	·00085	12·72	36·2	·00094	14·18
	18–24″	39·3	·00083	12·50	37·3	·00068	10·23
	24–30″	38·3	·00096	14·45	36·1	·00067	10·12
	30–36″	39·5	·00090	13·51	35·8	·00054	8·07
				76·29			79·43

Table I. Period (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		%Water on dry soil	$NaNO_3$ in dry soil		%Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
27th August 1925	0–6″	41·5	·00099	14·85	41·3	·0014	21·19
	6–12″	38·7	·00076	11·39	38·9	·0013	19·70
	12–18″	37·9	·00075	11·32	38·7	·0012	18·64
	18–24″	36·4	·00054	8·12	37·3	·00083	12·28
	24–30″	37·5	·00048	7·17	38·6	·0010	15·50
	30–36″	38·3	·00055	8·26	39·3	·0013	19·79
				61·11			107·10
3rd September 1925	0–6″	40·6	·0010	15·80	10·1	·0013	19·92
	6–12″	37·9	·00075	11·31	37·6	·0011	16·40
	12–18″	37·5	·00068	10·25	36·5	·00088	13·20
	18–24″	36·8	·00088	13·24	36·1	·00081	12·18
	24–30″	36·3	·00068	10·14	37·2	·00075	11·24
	30–36″	37·0	·00075	11·22	37·5	·00068	10·25
				71·96			83·19
10th September 1925	0–6″	36·0	.0011	16·18	36·4	·0011	16·23
	6–12″	33·1	·00079	11·85	33·5	·0010	15·81
	12–18″	33·3	·00072	10·86	33·1	·00079	11·81
	18–24″	33·6	·00079	11·88	33·3	·00066	9·87
	24–30″	40·0	·00078	11·51	37·6	·00068	10·25
	30–36″	38·4	·00076	11·36	38·5	·00070	10·34
				73·64			74·31
16th September 1925	0–6″	39·4	·00085	12·79	31·6	·00097	14·57
	6–12″	32·6	·00059	8·82	31·1	·00084	12·56
	12–18″	32·5	·00059	8·81	30·8	·00058	8·68
	18–24″	31·1	·00053	7·95	31·5	·00045	6·79
	24–30″	35·5	·00047	7·04	35·3	·00040	6·03
	30–36″	33·4	·00046	6·91	35·9	·00040	6·06
				52·32			54·69
23rd September 1925	0–6″	37·0	·00010	15·30	31·0	·0012	17·87
	6–12″	32·9	·00065	9·83	31·4	·00084	12·60
	12–18″	32·2	·00072	10·71	30·5	·00058	8·65
	18–24″	32·9	·00065	9·83	31·2	·00045	6·77
	24–30″	35·9	·00067	10·10	35·4	·00047	7·03
	30–36″	37·0	·00075	11·22	37·1	·00095	14·30
				67·02			67·22

Table I. Period (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925 – 8th April 1926 – contd.

Date	Depth	Unmanured plot: % Water on dry soil	Unmanured plot: $NaNO_3$ in dry soil, Grm. per 100 grm.	Unmanured plot: $NaNO_3$ in dry soil, Lb. per acre	Manured plot: % Water on dry soil	Manured plot: $NaNO_3$ in dry soil, Grm. per 100 grm.	Manured plot: $NaNO_3$ in dry soil, Lb. per acre
2nd October 1925	0 6"	28·9	·00038	5·68	31·9	·00071	10·71
	6 12"	29·8	·00051	7·64	28·4	·00050	7·53
	12 18"	30·4	·00051	7·68	28·2	·00044	6·58
	18 24"	31·1	·00039	5·80	30·4	·00070	10·56
	24 30"	35·1	·00040	6·02	34·2	·00053	7·96
	30 36"	37·1	·00041	6·13	31·4	·00046	6·98
				38·95			50·32
7th October 1925	0 6"	27·5	·00044	6·54	26·7	·00062	9·26
	6 12"	26·7	·00037	5·56	29·0	·00057	8·53
	12 18"	28·2	·00044	6·58	30·4	·00045	6·72
	18 24"	31·3	·00032	4·84	32·1	·00039	5·85
	24 30"	35·1	·00040	6·07	34·7	·00033	5·00
	30 36"	36·2	·00040	6·08	34·5	·00033	4·99
				35·67			40·35
14th October 1925	0 6"	27·8	·00044	6·56	24·8	·00055	8·18
	6 12"	26·7	·00037	5·56	25·7	·00043	6·42
	12 18"	28·2	·00031	4·70	30·3	·00032	4·79
	18 24"	29·6	·00025	3·81	30·0	·00032	4·78
	24 30"	33·9	·00033	4·96	33·3	·00033	4·93
	30 36"	34·7	·00033	5·00	29·5	·00032	4·76
				30·59			33·86
21st October 1925	0 6"	31·4	·00048	7·26	30·7	·00058	8·67
	6 12"	30·4	·00038	5·71	28·3	·00038	5·64
	12 18"	29·7	·00032	4·77	27·3	·00031	4·66
	18 24"	31·4	·00032	4·84	28·5	·00025	3·77
	24 30"	33·0	·00033	4·92	34·6	·00027	3·99
	30 36"	35·6	·00034	5·03	33·0	·00026	3·93
				32·56			30·66
28th October 1925	0 6"	29·8	·0013	19·09	28·6	·0020	30·20
	6 12"	29·3	·00076	11·10	27·2	·00099	14·89
	12 18"	28·5	·00063	9·43	26·1	·00086	12·89
	18 24"	29·9	·00025	3·82	26·9	·00056	8·35
	24 30"	32·9	·00026	3·93	30·7	·00064	9·63
	30 36"	31·6	·00026	3·89	31·9	·00058	8·76
				51·56			84·72

Table I. Period (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
4th November 1925	0–6″	25·2	·00079	11·87	24·1	·0011	16·63
	6–12″	25·1	·00073	10·94	25·1	·00055	8·20
	12–18″	25·4	·00055	8·23	26·2	·00055	8·29
	18–24″	28·3	·00056	8·17	26·7	·00068	10·16
	24–30″	30·2	·00051	7·67	28·7	·00069	10·39
	30–36″	30·9	·00045	6·75	28·4	·00056	8·48
				53·93			62·15
17th November 1925	0–6″	32·4	·00065	9·78	31·2	·00077	11·61
	6–12″	32·2	·00052	7·81	29·3	·00076	11·40
	12–18″	29·1	·00044	6·64	25·4	·00061	9·14
	18–24″	26·6	·00037	5·55	25·9	·00049	7·35
	24–30″	29·3	·00038	5·70	30·9	·00045	6·75
	30–36″	29·6	·00038	5·72	29·9	·00045	6·69
				41·20			52·94
25th November 1925	0–6″	32·9	·00059	8·84	31·9	·00071	10·71
	6–12″	34·2	·00046	6·96	30·0	·00057	8·61
	12–18″	32·9	·00046	6·87	30·4	·00045	6·72
	18–24″	29·5	·00038	5·71	29·4	·00038	5·71
	24–30″	31·3	·00039	5·81	32·8	·00046	6·87
	30–36″	31·6	·00039	5·82	32·3	·00046	6·84
				40·01			45·46
2nd December 1925	0–6″	28·5	·00050	7·55	28·4	·00056	8·48
	6–12″	29·4	·00044	6·65	29·8	·00051	7·64
	12–18″	28·4	·00044	6·59	30·3	·00077	11·51
	18–24″	29·6	·00051	7·63	29·9	·00051	7·64
	24–30″	29·4	·00051	7·61	32·9	·00059	8·85
	30–36″	31·3	·00045	6·78	33·8	·00053	7·93
				42·81			52·05
12th December 1925	0–6″	27·4	·00043	6·53	27·4	·00075	11·19
	6–12″	28·3	·00038	5·65	26·5	·00062	9·24
	12–18″	30·4	·00038	5·76	29·5	·00044	6·66
	18–24″	30·1	·00032	4·78	27·2	·00037	5·58
	24–30″	31·6	·00045	6·80	28·8	·00038	5·67
	30–36″	33·1	·00039	5·90	28·9	·00038	5·68
				35·42			44·02

Table I. Period (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926— contd.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: Lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: Lb. per acre
16th December 1925	0 6″	28·1	·00044	6·58	26·6	·00062	9·26
	6- 12″	23·2	·00044	6·58	26·4	·00049	7·39
	12 18″	28·7	·00044	6·61	25·5	·00043	6·40
	18 24″	30·9	·00045	6·75	30·2	·00045	6·71
	24 30″	30·8	·00051	7·71	28·3	·00050	7·55
	30 36″	32·5	·00052	7·83	29·8	·00044	6·67
				42·06			43·98
23rd December 1925	0 6	23·8	·00048	7·20	25·4	·00055	8·25
	6 12″	26·4	·00043	6·47	25·5	·00049	7·32
	12 18″	27·7	·00037	5·61	27·2	·00043	6·52
	18 24″	30·0	·00038	5·74	27·8	·00044	6·56
	24 30″	32·4	·00046	6·85	25·4	·00043	6·40
	30 36″	31·0	·00039	5·79	27·1	·00043	6·51
				37·66			41·54
28th December 1925	0 6″	27·2	·00050	7·45	24·7	·00061	9·08
	6 12″	27·5	·00044	6·54	24·0	·00054	8·12
	12- 18″	29·0	·00044	6·63	24·9	·00055	8·19
	18- 24″	30·8	·00045	6·75	26·2	·00055	8·30
	24 30″	29·4	·00038	5·70	26·5	·00049	7·39
	30 36″	32·1	·00039	5·85	29·3	·00051	7·60
				38·92			48·68
6th January 1926	0 6″	25·9	·00086	12·87	26·6	·00093	13·88
	6 12″	26·9	·00080	12·07	27·8	·0011	16·86
	12 18″	27·6	·00062	9·35	27·3	·00099	14·90
	18 24″	30·2	·00064	9·58	26·3	·00086	12·91
	24 30″	31·1	·00064	9·66	27·3	·00068	10·25
	30- 36″	30·4	·00064	9·60	27·2	·00068	10·24
				63·13			79·04
16th January 1926	0 6″	30·0	·0015	22·91	31·0	·0017	25·10
	6 12″	27·9	·0010	15·00	28·9	·0011	17·01
	12- 18″	26·9	·0011	16·70	28·0	·0010	15·01
	18 24″	27·7	·0010	14·96	31·5	·00078	11·64
	24 30″	29·3	·0010	15·21	28·6	·00076	11·33
	30– 36″	29·3	·0010	15·21	29·0	·00088	13·26
				99·99			93·38

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
21st January 1926	0—6″	23·4	·00084	12·54	24·9	·0013	20·03
	6—12″	22·3	·00074	11·17	23·2	·00057	8·53
	12—18″	21·0	·00082	12·15	23·6	·00084	12·58
	18—24″	23·1	·00083	12·51	23·0	·00071	10·71
	24—30″	26·5	·00062	9·24	25·5	·00061	9·15
	30—36″	26·2	·00074	11·07	24·2	·00060	9·04
				68·68			70·04
28th January 1926	0—6″	24·9	·00069	9·10	25·3	·00097	14·62
	6—12″	27·1	·00037	5·58	25·3	·00073	10·99
	12—18″	26·4	·00062	9·24	26·7	·00062	9·26
	18—24″	27·2	·00031	4·65	29·6	·00063	9·51
	24—30″	30·7	·00064	9·63	27·2	·00062	9·31
	30—36″	31·8	·00098	14·76	27·6	·00050	7·47
				52·96			61·16
3rd February 1926	0—6″	26·6	·00099	14·80	27·4	·0010	15·85
	6—12″	24·6	·00078	11·72	25·7	·00098	14·68
	12—18″	28·7	·00076	11·34	26·6	·00086	12·95
	18—24″	28·1	·00069	10·33	25·7	·00086	12·85
	24—30″	31·2	·00071	10·65	30·5	·00077	11·53
	30—36″	31·7	·00071	10·70	29·5	·00076	11·43
				69·54			99·29
12th February 1926	0—6″	25·6	·0010	15·57	24·2	·00096	14·46
	6—12″	23·8	·0013	18·89	23·3	·0014	21·49
	12—18″	24·6	·00091	13·61	23·5	·00090	13·47
	18—24″	22·9	·00095	14·26	22·3	·0010	15·07
	24—30″	23·4	·00095	14·33	26·4	·00092	15·84
	30—36″	24·1	·00084	12·64	23·5	·00078	11·67
				89·30			90·00
20th February 1926	0—6″	22·1	·00077	11·50	21·9	·00088	13·23
	6—12″	21·6	·00076	11·43	21·9	·0011	15·88
	12—18″	20·7	·00093	13·96	20·5	·0010	15·65
	18—24″	23·1	·00089	13·40	23·4	·0010	15·22
	24—30″	25·2	·00079	11·86	24·0	·0010	15·34
	30—36″	26·4	·00071	11·98	24·9	·00085	12·74
				73·23			88·06

TABLE I. PERIOD (a).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926— contd.

Date	Depth	UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
25th February 1926	0 6″	23·5	·00072	10·78	23·1	·00077	11·62
	6 12″	23·4	·00072	10·75	21·9	·00071	10·59
	12 18″	24·4	·00091	13·59	23·1	·00071	10·71
	18 24″	24·0	·00084	12·62	23·4	·00084	12·54
	24 30″	28·1	·00075	11·26	27·9	·00076	11·43
	30 36″	30·1	·00089	13·41	26·0	·00086	12·87
				72·41			69·76
4th March 1926	0 6″	23·2	·00066	9·81	22·7	·00053	8·01
	6 12″	24·9	·00067	10·01	22·1	·00059	8·84
	12 18″	24·9	·00067	10·01	22·9	·00053	8·03
	18 24″	24·2	·00078	11·75	22·1	·00047	7·07
	24 30″	26·2	·00074	11·06	24·4	·00054	8·15
	30 36″	26·4	·00068	10·16	27·4	·00056	8·38
				62·83			48·48
10th March 1926	0 6″	24·9	·00079	11·83	21·2	·00070	10·53
	6 12″	23·1	·00054	8·04	22·2	·00077	11·51
	12- 18″	22·7	·00053	8·01	23·2	·00072	10·74
	18 24″	25·2	·00061	9·12	22·1	·00059	8·85
	24 30″	28·0	·00069	10·32	25·2	·00060	9·94
	30 36″	30·8	·00077	11·56	26·4	·00062	9·24
				58·88			60·01
18th March 1926	0 6″	22·1	·00077	11·50	19·3	·0011	17·19
	6 12″	23·9	·00060	9·01	21·5	·0011	16·70
	12 18″	23·6	·00060	8·98	23·2	·00077	11·63
	18 24″	26·4	·00062	9·23	22·7	·00059	8·90
	24 -30″	28·2	·00063	9·40	23·9	·00060	9·01
	30 36″	31·4	·00065	9·69	23·5	·00078	11·65
				57·81			75·08
25th March 1926	0 6″	17·2	·00084	12·59	22·5	·00083	12·42
	6 12″	22·3	·00059	8·86	22·1	·00094	14·14
	12 18″	22·7	·00059	8·90	23·5	·00084	12·55
	18 24″	24·0	·00060	9·92	24·1	·00096	14·44
	24 30″	26·7	·00062	9·26	26·5	·00062	9·25
	30 36″	27·4	·00062	9·33	25·2	·00073	10·95
				57·96			73·75

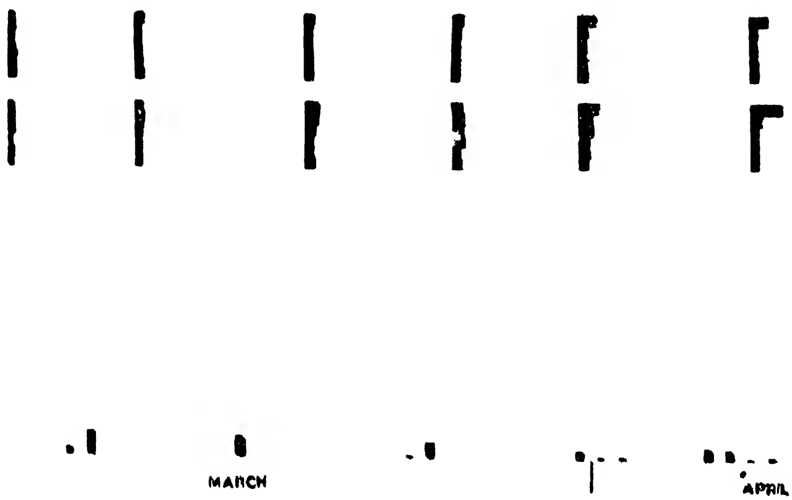
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TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926 concld.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
31st March 1926	0 6″	10·2	·0013	26·19	12·9	·0015	22·42
	6- 12″	22·0	·00076	11·15	21·2	·0010	15·78
	12 18″	24·6	·00060	9·07	23·2	·0011	16·09
	18 24″	24·4	·00060	9·06	23·8	·00084	12·59
	24 30″	28·0	·00069	10·32	25·6	·00085	12·82
	30 36″	28·0	·00075	11·25	25·9	·00067	10·11
				71·34			89·81
8th April 1926	0 6″	10·5	·0013	20·25	9·3	·0025	36·88
	6 12″	21·9	·00053	7·95	19·2	·00091	13·72
	12 18″	23·6	·00042	6·29	22·0	·00053	7·95
	18 24′	22·5	·00047	7·10	23·5	·00054	8·08
	24 30″	25·6	·00055	8·24	24·0	·00054	8·12
	30 36″	27·6	·00056	8·41	26·3	·00055	8·30
				58·24			83·05

The above figures are expressed in diagrammatic form in Chart I. It will be seen that when the experiment was first started the soil already contained an appreciable quantity of nitrate. This is obviously due to the fact that several inches of rain had already fallen. A comparison of the moisture content of the samples taken on 21st June 1925 with those taken at the beginning of the hot weather on 8th April 1926, *i.e.*, when the soil had been drying out for several months shows that the moisture in the lower depths was similar on both occasions. The rainfall up to 21st June 1925 had therefore only affected the moisture content of the top 6″ of soil and it is in this top 6″ that the greatest increase of nitrate has taken place. In the case of the unmanured plot there was no nitrate at all in the 3rd foot of soil but the manured plot contained nitrate at each depth sampled. The manured plot is seen to contain much more nitrate than the unmanured plot. Before the second sample was taken on 25th June 1925, a further 2-3″ of rain had fallen and this was sufficient to increase considerably the moisture at lower depths. This extra rainfall also largely increased nitrification and both plots contained at this time their maximum nitrate content.

The drains under the plots did not start flowing until 8th July. The drains are laid at a depth of 2′-6″ and on 8th July when they first started running the layer 2′—2′ 6″ deep held 32·5 and 31·4 per cent. of moisture in the manured and unmanured plots respectively. On the 1st July these same layers held 30·1 and 29·8 per cent. of moisture respectively and apparently drainage does not take place until this figure is exceeded. Although the drains did not flow until July 8th, yet a consideration of the analyses made on 25th June and 1st July shows that the moisture was steadily moving downwards taking with it the nitrate formed at the surface.

The drains ran practically continuously throughout July and the heavy rains between 7th and 13th July very largely depleted the nitrate stores in the soil. In the second half of July only a light sprinkling of rain was received. Nitrates again accumulated in the surface 6″ layer of both plots. On the 29th and 30th there was a fall of about 5″ of rain and the samples of 30th July were taken after this. It will be seen that the soil lost nearly all its nitrate. There appeared to be some increase in nitrates in the samples taken on the 13th August, but in general from this date onwards no further accumulation of nitrate took place in the soil. By October the surface soil had dried considerably. On October 15th a fall of $1\frac{1}{2}$″ rain occurred and there were further light falls on 20th and 28th October. An appreciable increase in the soil nitrate especially in the surface 6″ occurred as a result of these falls of rain. The chart will show other cases where a light fall of rain was followed subsequently by an increase in soil nitrate, *e.g.* the rainfall at the beginning of January is obviously connected with the nitrate increase in the samples taken on 16th January and subsequent dates and the increase in nitrate at the end of March and in April is also connected with the light rainfall received just previously.

Conclusion.

A consideration of the above results brings forth several definite points :

(1) Shortly after the onset of the rains nitrification becomes very active. The maximum amount of nitrate in the top 3 feet of soil was found on 25th June after about 6″ of rain had fallen. The unmanured and manured plots contained nitrate nitrogen equivalent to 240 lb. and 340 lb. nitrate of soda per acre in the top 3 feet respectively. Since the crop was sown on 19th June the presence of such large stores of nitrate in the soil at this particular time appears to be useless to the crop especially as only 30 – 40 lb. of it is present in the top 6″. If the crop could be sown earlier so that the plants are large enough to take advantage of the large stores of nitrate present at this time it would be of great advantage but unfortunately moisture conditions in the soil are rarely favourable for the very early sowing which would be necessary to enable the crop to develop in time to profit by the large stores of nitrate produced early in the rains.

(2) The effect of a heavy fall of rain in depleting the nitrate found in the soil is well seen in the Chart. Top-dressing with nitrates should obviously be done immediately after such heavy falls, as the growing crop is likely to be short of nitrate for some time after they occur.

(3) There appears to be a large loss of nitrate from the top 3 feet of soil during the rains. One can compute from Table I roughly the amount of nitrate of soda which is lost from the soil presumably by drainage during the duration of the experiment. The figures are roughly 480 and 620 lb. of nitrate of soda per acre for the unmanured and manured plots respectively. These figures have been obtained by noting the first maximum amount of nitrate found, *viz.*, on 25th June there were 240 and 340 lb. nitrate of soda present per acre in the top 3 feet of soil. On the 15th July these amounts had diminished to 131 and 169 lb. nitrate of soda a loss of 109 and 171 lb. respectively. On 22nd July the nitrate had increased to 188 and 284 lb. respectively and had diminished to 69 and 94 lb. by 3rd August a further loss of 119 and 190 lb. respectively. Proceeding in this way the total loss of nitrate of soda per acre from the unmanured and manured plots is found to be roughly 480 and 620 lb., respectively.

The results for the period (*b*), *viz.*, 16th April 1926 and 28th October 1926, are set out in Table II. This table is set out in the same manner as Table I but as explained previously four plots were under experiment during this period.

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
16th April 1926	0 6	6·9	·0012	17·89	8·5	·00076	11·31
	6 12	18·8	·00068	10·25	20·8	·00035	5·24
	12 18	23·2	·00030	4·47	23·0	·00024	3·57
	18 24	23·8	·00030	4·50	25·2	·00024	3·65
	24 30	24·4	·00030	4·53	26·2	·00018	2·77
	30 36	24·4	·00030	4·53	28·4	·00031	4·71
				46·17			31·28
30th April 1926	0 - 6	9·5	·00067	10·01	10·6	·00059	8·92
	6 12	23·6	·00042	6·28	21·4	·00024	3·57
	12 18	27·4	·00034	5·15	29·2	·00015	2·27
	18 24	30·2	·00032	4·79	28·4	·00019	2·86
	24 30	34·4	·00033	4·98	27·1	·00023	3·45
	30 36	28·4	·00031	4·71	27·6	·00027	4·01
				35·92			25·08
13th May 1926	0 6	9·1	·0010	15·31	10·0	·0010	15·48
	6 12	19·5	·00057	8·61	20·0	·00069	10·38
	12 18	23·0	·00048	7·14	24·9	·00036	5·46
	18 24	28·2	·00050	7·52	28·7	·00050	7·56
	24 30	30·6	·00038	5·77	28·2	·00044	6·58
	30 36	30·6	·00045	6·73	30·1	·00032	4·79
				51·08			50·25
21st May 1926	0 6	29·2	·0025	22·77	32·4	·0014	21·52
	6 12	26·8	·0033	50·07	31·3	·0015	23·25
	12 18	26·6	·00055	8·33	28·8	·00050	7·57
	18 24	28·2	·00057	8·52	27·4	·00050	7·46
	24 30	27·0	·00056	8·36	26·2	·00049	7·37
	30 36	26·1	·00055	8·29	27·9	·00050	7·50
				106·34			74·67
24th May 1926	0 6	25·6	·0026	38·47	27·6	·0035	51·30
	6 12	17·2	·00095	14·26	25·6	·0016	24·73
	12 18	21·1	·00064	9·83	22·8	·00095	14·26
	18 24	24·9	·00073	10·92	25·5	·00061	9·15
	24 -30	28·3	·00063	9·41	30·6	·00064	9·61
	30 -36	30·9	·00064	9·64	27·4	·00062	9·33
				92·53			119·38

PERIOD (*b*).

the period 16th April—28th October 1926.

CROPPED AREA

Unmanured plot			Manured plot		
% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre
8·5	·0012	18·24	7·1	·0014	20·94
21·0	·00047	7·0	17·3	·00078	11·77
24·5	·00042	6·34	20·8	·00058	8·72
30·1	·00038	5·78	23·10	·00054	8·03
31·9	·00039	5·88	24·9	·00030	4·55
33·4	·00040	5·96	26·5	·00025	3·70
		49·19			57·71
10·4	·00063	9·39	7·6	·0010	15·03
21·9	·00053	7·97	19·0	·00057	8·56
25·7	·00036	5·48	25·2	·00061	9·13
26·6	·00036	5·47	27·6	·00056	8·41
29·9	·00038	5·71	30·1	·00038	5·75
28·4	·00044	6·67	28·0	·00030	4·47
		40·69			51·35
11·4	·0010	15·73	9·1	·0011	16·84
17·8	·00056	8·45	15·0	·00096	11·47
24·7	·00042	6·35	21·3	·00058	8·77
25·1	·00043	6·38	29·9	·00051	7·64
23·3	·00036	5·37	24·7	·00048	7·26
25·2	·00036	5·47	25·2	·00043	6·38
		47·75			58·36
32·6	·0012	17·64	32·5	·002	29·35
30·9	·0015	23·14	21·2	.0012	17·52
28·5	·00075	11·32	26·1	·0011	16·56
29·1	·00076	11·39	26·8	·00099	14·83
30·5	·00058	8·65	27·1	·00050	7·44
30·4	·00058	8·64	28·5	·00063	9·44
		80·78			95·14
26·8	·0026	38·94	26·1	·0032	47·82
20·8	·00099	14·84	16·4	·0013	19·98
22·9	·00089	13·38	23·1	·00083	12·51
24·4	·00066	9·95	24·1	·00066	9·93
26·5	·00062	9·25	28·3	·00069	10·36
27·0	·00068	10·22	25·0	·00085	12·75
		96·58			113·35

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA — Unmanured plot: % Water on dry soil	Unmanured plot: $NaNO_3$ in dry soil, Grm. per 100 grm.	Unmanured plot: $NaNO_3$ in dry soil, lb. per acre	Manured plot: % Water on dry soil	Manured plot: $NaNO_3$ in dry soil, Grm. per 100 grm.	Manured plot: $NaNO_3$ in dry soil, lb. per acre
1st June 1926	0 6	20·0	·0028	41·56	20·8	·0028	41·94
	6 12	17·5	·00084	12·64	21·0	·0016	24·49
	12 18	24·1	·00090	13·54	24·9	·00085	12·75
	18 24	25·1	·00061	9·12	26·4	·00074	11·08
	24 30	27·9	·00062	9·37	29·8	·00045	6·68
	30 36	25·5	·00043	6·40	29·0	·00051	7·59
				92·63			104·53
4th June 1926	0 6	17·3	·0028	42·03	14·4	·0026	39·09
	6 12	17·6	·00056	8·44	17·7	·00067	10·13
	12 18	21·9	·00059	8·82	22·2	·00059	8·86
	18 24	22·2	·0010	15·04	22·8	·00095	14·26
	24 30	28·5	·00058	7·54	25·7	·00067	10·08
	30 36	28·8	·00044	6·62	22·8	·00065	9·79
				88·49			92·21
9th June 1926	0—6	12·8	·0019	28·81	13·6	·0028	41·94
	6—12	14·9	·0014	21·28	10·6	·0011	17·16
	12—18	21·2	·00070	10·52	19·7	·00092	13·80
	18—24	21·9	·00065	9·71	19·5	·00092	13·78
	24—30	28·4	·00050	7·53	20·2	·00069	10·40
	30—36	28·1	·00050	7·51	21·1	·00059	8·84
				85·36			105·92
16th June 1926	0—6	17·8	·0025	37·18	18·3	·0045	67·98
	6—12	24·0	·00066	9·92	24·0	·0029	43·32
	12—18	25·2	·00049	7·30	27·0	·0010	15·78
	18—24	28·2	·00069	10·35	29·3	·0015	15·21
	24—30	26·0	·00043	6·44	21·1	·00058	8·69
	30—36	28·6	·00044	6·61	29·4	·00051	7·61
				77·80			158·59
21st June 1926	0—6	15·3	·0031	46·03	16·4	·0035	53·29
	6—12	24·4	·0014	21·73	24·9	·0021	30·94
	12—18	29·2	·00051	7·59	28·5	·0016	24·51
	18—24	29·1	·00057	8·53	31·1	·0012	17·38
	24—30	30·7	·00058	8·66	29·6	·00063	9·53
	30—36	28·1	·00056	8·45	26·0	·00074	11·04
				100·99			146·69

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA					
UNMANURED PLOT			MANURED PLOT		
% Water on dry soil	NaNO₃ in dry soil: Grm. per 100 grm.	NaNO₃ in dry soil: lb. per acre	% Water on dry soil	NaNO₃ in dry soil: Grm. per 100 grm.	NaNO₃ in dry soil: lb. per acre
18·1	·0024	35·62	21·2	·0050	71·82
21·8	·00071	10·58	18·1	·0015	22·05
24·9	·00091	13·65	23·8	·0011	16·20
26·7	·00093	13·90	22·9	·00095	14·27
27·8	·00044	6·56	28·1	·00056	8·44
28·7	·00057	8·50	26·0	·00067	10·12
		88·81			142·90
14·7	·0023	34·32	12·6	·0017	25·54
18·6	·00074	11·09	18·0	·00090	13·56
23·6	·00054	8·09	21·0	·00058	8·74
21·8	·00047	7·05	22·9	·00059	8·92
26·8	·00049	7·42	24·7	·00054	8·17
25·2	·00091	13·68	24·0	·00054	8·11
		81·65			73·04
16·2	·0031	46·50	11·9	·0033	49·06
18·1	·0016	23·76	14·3	·0015	21·96
21·1	·00088	13·26	24·0	·00066	9·92
26·5	·00080	12·01	25·5	·00061	9·14
29·0	·00076	11·37	24·7	·00042	6·36
29·8	·00051	7·63	25·8	·00055	8·27
		114·53			104·71
21·0	·0026	38·49	20·8	·0045	68·13
25·2	·00097	14·59	27·4	·0019	27·99
26·6	·00049	7·40	27·7	·00081	12·16
27·6	·00037	5·61	27·4	·00050	7·46
27·7	·00031	4·68	30·1	·00045	6·70
28·3	·00031	4·70	28·3	·00050	7·53
		75·47			129·97
12·5	·0026	38·25	16·7	·0058	86·79
20·3	·0016	24·31	22·9	·0021	32·13
23·5	·00090	13·45	28·2	·0010	15·03
25·2	·00091	13·67	25·8	·00079	11·93
28·6	·00050	7·55	30·1	·00070	10·53
29·6	·00051	7·63	30·9	·00064	9·64
		104·86			166·05

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA — UNMANURED PLOT — % Water on dry soil	UNMANURED PLOT — $NaNO_3$ in dry soil — Grm. per 100 grm.	UNMANURED PLOT — $NaNO_3$ in dry soil — lb. per acre	MANURED PLOT — % Water on dry soil	MANURED PLOT — $NaNO_3$ in dry soil — Grm. per 100 grm.	MANURED PLOT — $NaNO_3$ in dry soil — lb. per acto
30th June 1926	0 6	11·8	·0033	49·02	12·3	·0047	70·00
	6 12	19·2	·0013	18·87	17·8	·0013	20·29
	12 18	23·4	·00048	7·16	21·1	·00058	8·75
	18 24	25·2	·00091	13·69	20·4	·0015	22·57
	24 30	24·4	·00042	6·34	22·9	·00059	8·92
	30 36	23·4	·00060	8·96	23·9	·00060	9·01
				104·04			139·54
9th July 1926	0 6	39·0	·0014	20·77	39·0	·0018	27·01
	6 12	36·9	·0022	32·61	37·9	·0016	24·66
	12 18	37·9	·0023	34·96	35·0	·0023	34·05
	18 24	38·7	·0021	31·06	36·8	·0020	30·54
	24 30	39·5	·0012	18·76	41·4	·0018	27·58
	30 36	40·8	·00091	13·71	38·4	·0015	22·71
				151·87			166·55
14th July 1926	0 6	39·5	·00097	14·59	39·2	·0014	21·84
	6 12	35·5	·00080	12·07	38·2	·0014	20·62
	12 18	37·1	·00082	12·25	39·0	·0023	35·29
	18 24	40·1	·0010	15·72	38·1	·0029	43·27
	24 30	38·5	·0019	28·96	40·5	·0028	42·07
	30 36	42·1	·0018	26·73	40·6	·0023	34·75
				110·32			197·84
19th July 1926	0 6	33·2	·0012	17·73	36·8	·0027	40·90
	6 12	33·4	·0010	15·78	33·0	·0018	27·54
	12 18	36·2	·00076	11·35	33·9	·0020	29·76
	18 24	39·4	·00083	12·51	40·4	·0023	35·74
	24 30	34·0	·00079	11·92	38·7	·0032	47·62
	30 36	35·3	·00067	10·05	39·0	·0028	41·50
				79·34			223·06
24th July 1926	0 6	31·5	·0016	24·39	33·2	·0034	51·21
	6 12	31·9	·0011	16·56	34·5	·0019	28·93
	12 18	34·3	·00066	9·95	34·5	·0018	26·94
	18 24	33·9	·00079	11·90	36·4	·0016	24·36
	24 30	32·8	·00098	14·73	40·1	·0017	25·32
	30 36	33·3	·00099	14·80	37·9	·0014	20·92
				92·33			177·68

PERIOD *(b)—contd*

the period 16th April—28th October 1926 contd.

CROPPED AREA

Unmanured plot			Manured plot		
% water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
11·2	·0027	40·84	12·0	·0054	80·86
18·4	·0016	23·82	18·5	·0020	30·66
23·3	·00060	8·95	24·0	·00060	9·01
26·0	·00067	10·12	24·9	·00061	9·10
25·7	·00049	7·33	27·0	·00043	6·50
25·7	·00049	7·33	27·4	·00037	5·60
		98·39			141·74
38·7	·0011	16·57	10·1	·0018	27·25
35·3	·0023	34·17	35·8	·0025	38·37
33·9	·0028	41·67	37·5	·0034	50·53
32·5	·0027	41·11	36·4	·0019	28·39
35·1	·0012	18·06	38·1	·0018	26·77
36·0	·0012	18·19	37·4	·0018	26·61
		169·77			197·92
38·4	·00083	12·39	39·4	·0017	25·00
36·2	·0010	15·21	35·1	·0013	20·27
32·4	·00065	9·79	35·6	·00094	14·09
38·8	·00062	9·32	36·5	·0015	23·38
42·1	·0011	16·05	37·6	·00075	11·29
41·3	·0012	18·76	40·8	0020	30·55
		81·52			124·38
32·8	·0014	21·60	33·3	·0020	29·59
32·7	·00099	14·90	33·3	·0014	21·70
33·2	·00078	11·82	33·8	·00092	13·87
35·2	·00080	12·06	34·9	·0013	20·02
40·1	·0011	16·77	38·8	·0015	22·80
38·3	·0018	26·82	39·2	·0012	18·73
		103·97			126·71
32·8	·0016	23·56	30·7	·0013	63·97
31·9	·0011	16·56	34·1	·0013	19·86
32·8	·00079	17·91	34·2	·00093	13·92
35·1	·00080	12·04	35·3	·0017	26·19
36·9	·0010	15·30	38·1	·0015	22·65
38·7	·0012	17·61	36·8	·0014	20·35
		102·98			166·94

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water in dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
29th July 1926	0–6	31·6	·0026	39·82	34·3	·0033	49·81
	6–12	31·9	·0016	24·34	32·4	·0031	46·93
	12–18	31·9	·0014	21·48	31·3	·0030	44·55
	18–24	35·1	·00073	10·32	34·8	·0028	42·01
	24–30	33·2	·0010	15·76	37·1	·0022	32·68
	30–36	31·3	·00090	13·55	37·8	·0021	31·83
				125·27			247·81
9th August 1926	0–6	39·5	·0012	18·76	38·4	·0012	18·61
	6–12	37·6	·0012	18·47	34·7	·0010	15·00
	12–18	36·4	·0010	15·21	36·8	·00095	14·25
	18–24	35·3	·0010	15·57	38·6	·0012	18·64
	24–30	33·6	·00086	12·85	39·6	·0014	20·89
	30–36	35·5	·00087	13·08	38·4	·0014	20·64
				93·94			108·03
14th August 1926	0–6	38·9	·00097	14·52	41·2	·0011	16·96
	6–12	36·1	·00094	14·15	39·6	·0011	15·41
	12–18	35·6	·0011	16·11	38·9	·0010	15·55
	18–24	37·6	·0010	15·42	38·8	·0012	17·61
	24–30	39·5	·0012	18·76	41·5	·0014	21·24
	30–36	38·9	·0012	18·68	40·5	·0017	26·28
				97·64			114·05
19th August 1926.	0–6	40·7	·00084	12·65	39·9	·00091	13·60
	6–12	35·1	·00080	12·01	39·5	·00090	13·55
	12–18	35·7	·00067	10·08	37·4	·00082	12·28
	18–24	39·1	·00069	10·39	40·1	·00084	12·57
	24–30	40·3	·00063	9·44	41·6	·00099	14·89
	30–36	37·6	·00082	12·31	43·1	·0014	20·43
				66·91			87·32
24th August 1926.	0–6	38·2	·0012	17·50	39·0	·0011	16·59
	6–12	34·9	·00080	12·01	37·1	·00095	14·30
	12–18	37·9	·00068	10·28	37·6	·00075	11·29
	18–24	37·8	·00068	10·27	39·3	·00069	10·41
	24–30	40·1	·00070	10·47	39·6	·0011	16·71
	30–36	37·0	·00068	10·19	39·0	·0017	25·95
				70·72			95·25

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA					
Unmanured plot			Manured plot		
% Water on dry soil	NaNO₃ in dry soil: Grm. per 100 grm.	NaNO₃ in dry soil: lb. per acre	% Water on dry soil	NaNO₃ in dry soil: Grm. per 100 grm.	NaNO₃ in dry soil: lb. per acre
32·1	·0030	44·85	32·2	·0027	40·99
30·0	·0017	24·88	31·9	·0022	33·12
32·5	·00098	11·68	31·8	·0022	33·06
33·3	·0014	21·69	31·6	·0019	29·14
33·3	·0016	23·67	34·2	·0019	28·84
31·8	·0015	23·32	35·1	·0019	29·08
		153·09			194·23
38·1	·00082	12·36	41·2	·0013	19·06
34·7	·00080	12·00	39·0	·0014	20·77
35·3	·00080	12·05	36·4	·0012	18·25
36·4	·00068	10·11	37·0	·0010	15·31
37·5	·00096	14·34	37·8	·0014	20·55
38·4	·00089	13·42	38·9	·0014	20·74
		71·31			114·68
37·6	·0011	16·41	39·0	·0013	19·74
34·3	·0011	15·92	37·1	·0011	16·34
35·1	·0010	15·02	35·8	·0010	15 68
36·4	·00088	13·18	36·4	·0010	15·21
37·1	00088	13·28	39·2	·0011	16·62
37·5	·00096	14·35	39·3	·0014	20·82
		88·16			103·81
37·6	·00055	8·21	41·6	·0011	15·96
36·4	·00054	8·11	37·4	·00095	11·33
33·1	·00052	7·86	37·1	·00082	12·21
34·7	·00067	9·99	35·5	·00074	11·07
33·6	·00059	8·89	35·4	·00094	14·07
35·1	·00067	10·01	37·6	·00089	13·34
		53·07			80·98
35·5	·00080	12·08	39·9	·00091	13·60
33·3	·00085	12·82	37·0	·00082	12·21
33·4	·00072	10·85	36·1	·00067	10·11
33·6	·00059	8·90	34·9	·00067	10·01
38·0	·00068	10·28	37·8	·0015	22·60
37·1	·00075	11·24	37·5	·0016	21·62
		66·17			93·15

Table II

Showing nitrate and moisture content of soil throughou

Date	Depth	UNCROPPED AREA					
		Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
2nd September 1926.	0 6	38·1	·00082	12·36	40·5	·00098	14.72
	6 12	36·3	·00068	10·14	36·8	·00075	11·19
	12 18	38·7	·00069	10·35	37·3	·00061	9·21
	18 24	39·7	·00070	10·47	37·6	·00068	10·26
	24 30	36·9	·00054	8·11	38·8	·00069	10·37
	30 36	36·2	·00067	10·12	37·9	·00062	9·25
				61·58			65·00
8th September 1926.	0 6	[illegible]	·00095	11·33	37·3	·0010	15·33
	6 12	34·1	·00079	11·92	36·5	·00081	12·19
	12 18	34·6	·00073	10·97	34·8	·00067	9·99
	18 24	37·1	·00061	9·21	35·1	·00067	10·03
	24 30	39·9	·00056	8·37	41·4	·00071	10·62
	30 36	37·1	·00075	11·24	41·8	·00085	12·78
				66·04			70·94
16th September 1926.	0 6	34·4	·00093	13·95	36·4	·0020	30·42
	6 12	32·3	·00071	10·72	33·0	·0010	15·72
	12 18	31·1	·00053	7·94	33·4	·00053	7·90
	18 24	36·0	·00054	8·09	34·7	·00053	7·99
	24 30	39·9	·00063	9·46	37·9	·00062	9·24
	30 36	39·5	·00076	11·46	38·1	·00069	10·29
				61·62			81·56
22nd September 1926.	0 6	34·7	·0021	31·02	35·8	·0024	35·34
	6 12	31·6	·00071	10·66	34·4	·0010	14·94
	12 18	34·1	·00060	8·94	34·4	·00071	10·60
	18 24	35·6	·00074	11·08	33·6	·00053	7·90
	24 30	39·8	·00056	8·35	39·9	·00077	11·51
	30 36	10·7	·00070	10·54	38·3	·0014	21·67
				80·59			101·96
28th September 1926.	0 6	32·8	·00078	11·76	33·9	·0011	15·84
	6 12	32·5	·00046	6·84	32·8	·00052	7·84
	12 18	33·9	·00040	5·94	34·1	·00046	6·95
	18 24	36·4	·00034	5·07	33·5	·00053	7·90
	24 30	37·9	·00048	7·20	37·3	·00041	6·14
	30 36	41·0	·00070	10·58	40·6	·00056	8·44
				47·39			53·11

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA					
UNMANURED PLOT			MANURED PLOT		
% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
36·3	·00088	13·16	39·8	·0011	16·74
33·5	·00079	11·85	36·2	·00094	14·17
35·4	·00067	10·06	37·1	·00075	11·21
32·2	·00071	10·73	35·8	·00060	9·07
37·4	·00068	10·24	39·5	·00069	10·42
39·8	·00077	11·52	40·9	·00070	10·56
		67·56			72·17
34·6	·00080	11·97	39·4	·00097	14·52
32·3	·00065	9·75	33·7	·00066	9·89
34·8	·00067	9·99	35·2	·00067	10·03
33·2	·00066	9·84	35·8	·00054	8·08
36·2	·00054	8·10	37·6	·00055	8·21
36·9	·00061	9·17	37·4	·00055	8·21
		58·82			58·94
34·1	·00066	9·93	35·6	·00094	14·11
32·0	·00052	7·78	34·4	·00066	9·96
31·9	·00052	7·78	33·6	·00053	7·90
32·5	·00046	6·84	35·8	·00040	6·06
36·2	·00047	7·08	37·4	·00041	6·13
37·9	·00048	7·19	39·2	·00069	10·41
		46·60			51·57
33·6	·00066	9·87	37·0	·0014	20·40
32·1	·00052	7·79	35·0	·00087	13·02
33·1	·00059	8·86	33·7	·00079	11·86
37·0	·00048	7·14	35·3	·00060	9·04
35·4	·00047	7·03	40·1	·00056	8·38
35·6	·00054	8·05	40·1	·00056	8·37
		48·74			71·07
31·2	·00039	5·80	30·9	·00064	9·64
31·3	·00039	5·80	31·9	·00052	7·78
33·5	·00033	4·93	32·5	·00039	5·85
33·5	·00026	3·95	32·2	·00032	4·87
34·2	·00026	3·98	38·7	·00028	4·14
36·6	·00027	4·06	37·7	·00027	4·11
		28·52			36·39

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
5th October 1926.	0 -- 6	35·3	·0013	19·09	36·1	·0014	21·26
	6 - 12	33·1	·00092	13·81	33·2	·0010	15·75
	12 18	33·9	·00059	8·91	32·8	·00052	7·86
	18 --24	36·5	·00054	8·13	32·6	·00046	6·84
	24 --30	38·1	·00055	8·23	36·6	·00041	6·11
	30 36	40·1	·00056	8·38	38·1	·00069	10·29
				66·55			68·11
13th October 1926.	0 — 6	32·2	·00091	13·66	32·1	·0012	18·51
	6 -12	32·7	·00065	9·89	32·5	·00065	9·77
	12 -18	35·0	·00040	6·00	33·5	·00059	8·89
	18 24	37·7	·00041	6·16	36·1	·00054	8·10
	24 -30	38·2	·00041	6·18	36·9	·00054	8·15
	30 -36	40·4	·00056	8·41	38·6	·00090	13·44
				50·30			66·86
20th October 1926.	0 -- 6	25·2	·00067	10·03	26·6	·00062	9·25
	6 -12	27·3	·00050	7·47	30·5	·00038	5·77
	12—18	32·8	·00039	5·88	32·7	·00033	4·89
	18 -24	35·5	·00033	5·02	34·7	·00040	6·00
	24 -30	36·8	·00034	5·08	36·5	·00034	5·07
	30 --36	38·0	·00041	6·17	36·7	·00041	6·10
				39·62			37·08
28th October 1926.	0 - 6	21·9	·00059	8·82	22·8	·00053	8·02
	6 -12	27·3	·00050	7·46	26·3	·00043	6·45
	12 -18	31·5	·00019	2·91	32·5	·00039	5·86
	18 24	33·4	·00033	4·93	34·2	·00033	4·97
	24 -30	37·8	·00041	6·16	35·5	·00033	5·03
	30 -36	35·9	·00034	5·04	36·0	·00034	5·05
				35·32			35·38

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA					
Unmanured plot			Manured plot		
% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre
31·2	·00054	8·10	36·0	·00074	11·12
32·8	·00052	7·84	31·3	·00064	9·66
31·8	·00039	5·83	33·2	·00052	7·88
31·9	·00039	5·84	35·3	·00054	8·04
36·0	·00034	5·05	36·6	·00047	7·11
37·7	·00041	6·16	36·5	·00041	6·08
		38·82			49·89
32·5	·00059	8·79	33·7	·00092	13·84
31·9	·00045	6·81	31·0	·00071	10·60
32·5	·00046	6·84	34·3	·00040	5·97
32·8	·00039	5·89	36·1	·00040	6·07
35·6	·00020	3·02	37·3	·00041	6·13
36·9	·00020	3·06	36·5	·00041	6·09
		34·41			48·70
24·9	·00036	5·46	27·5	.00031	4·67
28·4	·00038	5·64	29·6	·00038	5·71
30·7	·00038	5·78	33·0	·00033	4·91
31·2	·00052	7·73	34·6	·00020	3·00
32·0	·00045	6·83	35·3	·00033	5·02
35·1	·00040	6·01	34·9	·00033	5·01
		37·45			28·32
23·3	·00030	4·47	22·0	·00041	6·18
27·5	·00031	4·66	26·7	·00044	6·54
29·4	·00025	3·80	28·0	·00044	6·56
31·1	·00039	5·79	30·8	·00032	4·81
37·5	·00034	5·13	32·8	·00033	4·99
34·1	·00040	5·96	32·7	·00039	5·88
		29·81			34·87

The above figures are set out diagrammatically in Chart II.

The first interesting point in regard to the above table arises out of the first two sets of analyses carried out on 16th April 1926 and 30th April 1926 respectively. By comparison with the figures for the same plots in Table I, it will be seen that between 8th to 16th April 1926 a distinct loss of nitrate has taken place in these plots and on 30th April 1926 the loss is much greater, being particularly marked in the surface 6". Since there was no drainage at this time and no crop on the land, the nitrate has either suffered denitrification or has undergone transformation into some other compound.

The slight falls of rain in early April amounting to about 1" in all have caused a distinct increase in the nitrate content of the soil sampled on 13th May 1926. Yet at the date of sampling, the surface soil only contained from 9 to 10 per cent. moisture. This is too low a content to allow of nitrification and it would appear that nitrification must be a fairly rapid process and that the rain falling between 7th and 12th May was sufficient to raise the moisture say of the top 1 or 2" of soil to the necessary content for nitrification and that this process set in almost immediately.

Before the next sample was taken on the 21st May nearly 5" of rain fell. This amount of rain at such a date is abnormal at Nagpur. It is interesting to note that it only affected the moisture content of the top 18" of soil. On the unmanured plot set apart for cropping, it appears to have affected the moisture content throughout the top three feet when the figures are compared with those of the sample taken on the 13th May. These latter figures appear to be low, however, and comparison with the sample taken on 16th and 30th April indicate that this 5" of rainfall has not affected the soil below 18" in depth.

The nitrate content of the soil showed a large increase as a result of this 5" fall of rain. On the 21st and 22nd May there was a further fall of $\frac{3}{4}$" of rain. The plots were again sampled on the 24th May and the top 18" of soil had dried out considerably as a result of the $2\frac{1}{2}$ days intervening dry weather. The nitrates, however, still further increased in amount and Chart II indicates clearly that this extra nitrate formation has taken place in the top 6" of soil. Moreover, it is obvious that more nitrification has taken place on the manured than on the unmanured plots. There was practically no more rain until the 1st July except for a few very light showers. The soil steadily dried out as evidenced by all the samples taken up to and including those of 9th June. The nitrate remained fairly constant from 24th May to 1st June except for a large gain in the surface 6" of the manured plot destined for cropping. In the sample taken on the 4th June this plot again behaved abnormally losing about $\frac{1}{2}$ its nitrate in 3 days, whereas the nitrate content of the other plots remained fairly constant. The loss of nitrate in this one plot was undoubted, being far outside the experimental error and is difficult to account for. After this date there was in general a fairly steady gain in nitrate in all the plots right up to the end of June. Yet the

moisture content of the surface soil throughout this month was usually between 12 and 16 per cent. Black cotton soil with this content of moisture appears very dry and work in this laboratory in the past has indicated that no nitrification takes place in the soil when the moisture content is as low as this. But in the field nitrification obviously does take place under these conditions. In the samples taken on 16th June, there is a distinct increase in the nitrate content over those taken on the 9th June and it seems hardly possible that this increase could have been due to the ·05″ of rain received on the night of the 15-16th June—a few hours before the samples of the 16th were taken. The figures and Chart for June again show clearly that the nitrates are being formed mainly in the top 6″ of soil and that the manured plots are richer in nitrates than the unmanured plots.

The rains broke in full force early in July and approximately 12″ of rain fell between the 1st and 9th July on which latter date the next samples were taken. The Table shows that on this date the moisture content throughout the whole 3 feet depth was uniform in the case of each plot, running from 35-40 per cent. The nitrate was more or less evenly distributed throughout the 3 feet layer of soil, as is well seen in Chart II. There was, moreover, a still further increase in the total nitrate content of the soil. This increase probably took place between the date of the last sampling 30th June and the heavy rainfall recorded at 8 A.M. on the 4th July and possibly to some extent on the 6th and 7th July when there was a slight break in the rains. The drains began running on the 10th July and this flow was kept up in full force by a further fall of over 6″ of rain before the next samples were taken on the 14th July. A large amount of nitrate passed away in the drainage water and no doubt much more passed below the reach of the drains. In consequence, the nitrate content of three of the plots suffered a large loss; yet strangely enough the uncropped manured plot showed an actual gain of nitrate. Only a few light showers fell between the 14th and 19th July, on which latter date the next samples were taken. The drains ceased to flow on the 15th and did not run again until early in August. On the 19th July the moisture content of the top one foot of soil was 3 to 6 per cent. less than on the 14th July. Nitrification had obviously restarted as shown by the increase in the nitrate content of the top 6″ in each plot. There was distinctly less nitrate in the bottom foot of the uncropped unmanured plot than was present on the 14th July. Except for a very light shower of ·03″ on the 23rd, no rain fell between the 19th July and the date of the next sampling—24th July. Nitrification had gone on distinctly in the top 6″ in all cases as shown by the increase in nitrates in that layer and this was particularly marked in the two manured plots. The uncropped manured plot, however, showed a loss of total nitrate in the whole 3 feet since the previous sampling. Since there was no drainage at this time, it would appear that denitrification has taken place.

Nearly an inch of rain fell before the date of the next sampling on the 29th July and on this date there was a considerable increase of nitrate in all the plots since

the previous sampling. The 1″ of rain, however, had washed a good deal of the surface nitrate down into the second foot.

A further 6″ of rain fell before the next samples were taken on 9th August. The flow from the drains restarted on the 4th August.

It will be seen from Table II and from Chart No. II that much loss of nitrate had taken place from the soil. Rain fell more or less continuously throughout the month, the drains ran regularly and the nitrate content of all the plots showed a steady fall throughout August. From the 23rd to 26th of the month there was a slight break in the rains and in the samples taken on the 24th a very slight recovery of the nitrate content was indicated. Throughout the whole of August the moisture content in all the plots through the top 3 feet was almost always over 35 per cent. and frequently reached 40 per cent.

The drains were still running feebly when the next set of samples was taken on the 2nd September and a further slight diminution of the nitrate content of the soil was observed. The crop at this time was now becoming quite big and throughout September and the first half of October the nitrate content of the cropped plots was steadily less than that of the uncropped plots. The difference was small but we think significant and it is especially apparent if the top foot of soil only is considered. It is only natural as the roots of the cotton plant are probably mainly distributed in the top foot of soil. Drainage ceased after about the 4th September. There was a fall of 2″ of rain on the 10th of this month and a few light showers a few days later. The effect of this rain was distinct in increasing nitrification in the surface 6″ in the samples taken on the 16th and 22nd September. There was practically no more rain till the 3rd October and there was no flow from any of the drains. Yet when the next sample was taken on the 28th September all 4 plots had suffered a heavy loss of nitrate. In the case of the cropped plots one might have expected this, but in the case of the uncropped ones it is difficult to account for this loss unless we assume that denitrification was taking place. There was a fall of $1\frac{1}{4}$″ of rain on the 3rd October and this caused a small amount of nitrification as shown by the analyses made on the 5th of that month.

No rain fell after the 9th October and when samples were taken on the 20th October, only very small amounts of nitrate were left in any of the plots. By this time, the water content of the soil had considerably diminished, the surface soil in particular having lost a large amount of water.

Conclusions.

The comparison between the figures for 1925 and 1926 is not complete, since in 1925 the first samples were not taken until 21st June, whereas the 1926 series began in April. The maximum nitrate content of the plots was reached very quickly in 1925, *viz.*, on the 25th June. This was probably due to the frequent light showers in May and to the almost regular showers with no excessive falls in the first 3 weeks of June. The increase in nitrate in 1926 was much less sudden and all throughout 1926 the plots contained distinctly less nitrate than in 1925. This is probably

due to the fact that July 1926 was much wetter than July 1925, 21″ and 15·5″ of rain respectively falling in these 2 months. The rainfall in July 1926 was also more or less continuous and the continual drainage through the soil did not allow of the accumulation of nitrates even if they were actually formed.

2. The loss of nitrate on each of the four plots can be computed in the same way as was done on page 173 for period (*a*).

The losses are as follows in lb. nitrate of soda per acre.

Unmanured uncropped plot—229.
Manured uncropped plot—348.
Unmanured cropped plot—268.
Manured cropped plot—374.

These figures are distinctly less than the losses in the previous year. These figures are, of course, much lower than the actual losses which take place since we have only taken note of large losses and also our analyses were not done at sufficiently short intervals to follow all the changes in nitrate content which take place.

From a consideration of the foregoing results, it would appear to be indicated that nitrification takes place only in the rains and that at the end of the rains when the soil dries out, the process ceases. In our experiments it would appear that the heavy rains washed out the nitrate and from other causes also the nitrate diminished, so that during the cold weather only very small amounts of nitrate were present in the soil. In our experiments, however, the crop was not removed till mid November and hence the land received no cultivation after the cessation of the rains. Under normal conditions, however, if a cold weather crop is to be sown, the land is harrowed and ploughed after the rains in preparation for that crop. It appeared necessary to see whether under these conditions any nitrate was present in the soil in the cold weather. The effect of this is seen in period (*c*).

PERIOD (*c*). NOVEMBER 1ST 1926 TO DATE (JANUARY 1927).

As explained on page 158 the following plots were included in the experiments from November 1st onwards.

1. Uncropped unmanured uncultivated.
2. Uncropped manured uncultivated.
3. Cropped unmanured uncultivated.
4. Cropped manured uncultivated.
5. Uncropped unmanured cultivated.
6. Uncropped manured cultivated.
7. Plot III, uncropped unmanured cultivated.

Plots 1, 2, 3 and 4 were the same plots as had been sampled in period (*b*) and plots 5 and 6 were portions of plots (1) and (2) respectively. As above stated, the cultivation on these was very deficient as it was taken in hand too late.

The results are set out in Table III and in the Chart II. It will be seen from the Table that all the above 6 plots were not sampled at each sampling. Thus on

TABLE

Period

Date	Depth	Uncropped area — Uncultivated — Unmanured — % water on dry soil	NaNO₃ in dry soil — Grm. per 100 grm.	NaNO₃ in dry soil — Lb. per acre	Manured — % water on dry soil	NaNO₃ in dry soil — Grm. per 100 grm.	NaNO₃ in dry soil — Lb. per acre	Cultivated — Unmanured — % water on dry soil	NaNO₃ in dry soil — Grm. per 100 grm.	NaNO₃ in dry soil — Lb. per acre
1	2	3	4	5	6	7	8	9	10	11
1st November 1926.	0 -6	20·9	·00087	13·0	23·3	·00054	8·0	19·1	·00069	10·3
	6 -12	27·2	·00043	6·5	26·9	·00025	3·7	24·0	·00052	7·8
	12 -18	30·5	·00032	4·8	30·0	·00013	1·9	28·4	·00038	5·6
	18 -24	34·2	·00033	5·0	35·7	·00034	5·0	29·4	·00032	4·7
	24 -30	39·9	·00034	5·2	36·1	·00034	5·0	30·3	·00032	4·8
	30 -36	38·5	·00034	5·2	33·5	·00033	4·9	27·5	·00031	4·7
				39·7			28·5			37·9
13th November 1926.	0 -6	16·5	·00055	8·3	16·7	·00067	10·0	..	..	..
	6 -12	21·4	·00048	7·2	22·0	·00047	7·1	..	..	..
	12 -18	31·7	·00052	7·8	27·0	·00049	7·4	..	..	..
	18 -24	33·9	·00033	4·9	31·0	·00045	6·7	..	..	..
	24 -30	33·4	·00039	5·9	36·4	·00041	6·1	..	..	..
	30 -36	40·2	·00042	6·3	34·7	·00040	6·0	..	..	..
				40·4			43·3			
15th November 1926.	0 -6	23·9	·00042	6·3	21·0	·00058	8·7	16·2	·0011	16·5
	6 -12	28·5	·00031	4·7	26·1	·00043	6·4	24·6	·00048	7·3
	12 -18	33·9	·00040	5·9	30·5	·00032	4·8	26·6	·00037	5·5
	18 -24	33·9	·00033	4·9	30·0	·00032	4·8	28·0	·00037	5·6
	24 -30	37·5	·00041	6·2	30·7	·00032	4·8	26·3	·00037	5·5
	30 -36	36·8	·00034	5·1	31·4	·00033	5·0	28·0	·00037	5·6
				33·1			34·5			46·0
24th November 1926.	0 -6	21·1	·00041	6·1	20·1	·00052	7·8	16·2	·0010	15·0
	6 -12	27·1	·00037	5·6	27·6	·00044	6·5	25·4	·00049	7·3
	12 -18	28·9	·00038	5·7	29·0	·00038	5·7	23·8	·00042	6·3
	18 -24	33·0	·00039	5·9	32·4	·00033	4·9	28·2	·00038	5·6
	24 -30	34·2	·00053	8·0	35·1	·00033	5·0	34·0	·00040	6·0
	30 -36	34·3	·00040	6·0	32·6	·00033	4·9	33·1	·00039	5·9
				37·3			34·8			46·1

III

(c)

CROPPED AREA											
CULTIVATED			UNCULTIVATED AFTER REMOVAL OF CROP						UNCROPPED, CULTIVATED		
MANURED			UNMANURED			MANURED			UNMANURED		
% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
12	13	14	15	16	17	18	19	20	21	22	23
21·6	·00053	7·9	..	..	..	..	..	..	28·2	·0010	60·1
24·8	·00049	7·3	..	..	..	..	..	..	29·9	·0023	34·4
28·8	·00038	5·7	..	..	..	..	..	..	34·3	·0012	17·9
30·3	·00032	4·8	..	..	..	..	..	..	36·3	·00094	14·2
34·4	·00040	6·0	..	..	..	..	..	..	38·5	·00083	12·4
34·8	·00040	6·0	..	..	..	..	..	..	39·2	·00083	12·5
		37·7									151·5
..	..	..	18·9	·00034	5·1	17·6	·00039	5·9	..	..	..
..	..	..	25·6	·00030	4·6	24·0	·00036	5·4	..	..	..
..	..	..	30·0	·00032	4·8	26·0	·00043	6·4	..	..	..
..	..	..	30·9	·00038	5·8	28·4	·00031	4·7	..	..	..
..	..	..	31·5	·00039	5·8	32·0	·00032	4·9	..	..	..
..	..	..	31·4	·00032	4·8	31·4	·00032	4·8	..	..	..
					30·9			32·1			
16·6	·00072	10·8	..	..	..	..	..	..	19·4	·0046	69·0
25·0	·00049	7·3	..	..	..	..	..	..	28·2	·0025	37·6
26·5	·00037	5·5	..	..	..	..	..	..	32·7	·0014	21·6
29·9	·00038	5·7	..	..	..	..	..	..	31·6	·0012	18·4
29·6	·00038	5·7	..	..	..	..	..	..	35·1	·00094	14·0
30·1	·00045	6·7	..	..	..	..	..	..	37·7	·00082	12·3
		41·7									172·0
16·8	·00055	8·3	..	..	..	..	..	..	29·3	·0038	57·0
22·2	·00041	6·2	..	..	..	..	..	..	29·6	·0016	24·8
28·4	·00044	6·6	..	..	..	..	..	..	29·7	·0020	29·6
27·2	·00043	6·5	..	..	..	..	..	..	30·1	·0015	23·0
31·0	·00045	6·7	..	..	..	..	..	..	34·0	·00079	11·9
28·5	·00044	6·6	..	..	..	..	..	..	35·0	·00080	12·0
		40·9									158·3

Table

Period

Date	Depth	UNCROPPED AREA								
		Uncultivated						Cultivated		
		Unmanured			Manured			Unmanured		
		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
1	2	3	4	5	6	7	8	9	10	11
29th November 1926.	0 6	20·5	·00063	9·5	19·4	·00086	12·9	..	..	..
	6 12	28·4	·00044	6·6	25·9	·00049	7·3	..	..	..
	12 18	30·8	·00038	5·8	29·1	·00044	6·6	..	..	..
	18-24	27·7	·00037	5·6	32·8	·00052	7·8	..	..	..
	24-30	35·7	·00047	7·1	34·6	·00046	7·0	..	..	..
	30-36	34·7	·00040	6·0	34·4	·00033	5·0	..	..	..
				40·6			46·6			
2nd December 1926.	0 6	17·7	·00056	8·5	20·3	·00040	6·0	13·0	·00075	11·2
	6 12	27·9	·00056	8·4	25·3	·00043	6·4	25·1	·00049	7·3
	12 18	31·5	·00058	8·7	26·7	·00037	5·6	26·8	·00043	6·5
	18 24	28·3	·00056	8·5	27·8	·00050	7·5	28·3	·00044	6·6
	24 30	31·1	·00058	8·7	34·1	·00046	6·9	34·7	·00040	6·0
	30-36	30·0	·00051	7·7	31·4	·00045	6·8	35·3	·00054	8·0
				50·5			39·2			45·6
7th December 1926.	0-6	17·6	·00067	10·0	15·5	·00066	9·9	11·7	·00074	10·1
	6 12	24·9	·00049	7·3	23·9	·00048	7·2	23·1	·00042	6·2
	12-18	26·0	·00049	7·4	25·2	·00049	7·3	28·4	·00038	5·6
	18-24	31·8	·00045	6·8	28·5	·00050	7·5	30·0	·00045	6·7
	24 30	35·5	·00040	6·0	33·3	·00053	7·9	36·3	·00047	7·1
	30-36	33·3	·00039	5·9	33·1	·00046	6·9	34·6	·00040	6·0
				43·4			46·7			41·7
17th December 1926.	0-6	18·7	·00091	13·7	20·0	·0018	27·6	19·5	·00057	8·6
	6-12	24·8	·00042	6·3	21·8	·00047	7·0	24·7	·00042	6·4
	12-18	29·9	·00038	5·7	28·0	·00037	5·6	30·0	·00045	6·7
	18-24	32·4	·00039	5·9	27·3	·00031	4·7	31·3	·00045	6·8
	24-30	35·0	·00040	6·0	31·4	·00039	5·8	35·0	·00040	6·0
	30-36	34·3	·00039	6·0	32·2	·00039	5·8	36·3	·00040	6·1
				43·6			56·5			40·6

III—*contd.*

(*c*)—contd.

Cropped area											
Cultivated			Uncultivated after removal of crop						Uncropped, cultivated		
Manured			Unmanured			Manured			Unmanured		
% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 Grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm per. 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
12	13	14	15	16	17	18	19	20	21	22	23
..	..	..	19·8	·00029	4·3	22·2	·00041	6·2	..	..	..
..	..	..	23·5	·00030	4·5	25·8	·00037	5·5	..	..	..
..	..	..	26·1	·00037	5·5	25·3	·00043	6·4	..	..	..
..	..	..	24·7	·00030	4·5	28·3	·00044	6·6	..	..	..
..	..	..	29·7	·00032	4·8	34·3	·00040	6·0	..	..	..
..	..	..	31·3	·00032	4·8	33·7	·00033	4·9	..	..	..
					28·4			35·6			
16·8	·00100	15·0	..	..	..	..	..	..	23·9	·0036	54·0
25·1	·00061	9·1	..	..	..	..	..	..	26·8	·0012	17·6
26·9	·00043	6·5	..	..	..	..	..	..	28·2	·0012	17·8
27·6	·00044	6·5	..	..	..	..	..	..	30·0	·0011	17·2
30·0	·00045	6·7	..	..	..	..	..	..	33·9	·00092	13·9
33·5	·00039	5·9	..	..	..	..	..	..	33·9	·00092	13·9
		49·7									131·4
13·6	·00091	13·7	..	..	..	..	..	..	22·9	·0038	57·5
24·6	·00093	10·9	..	..	..	..	..	..	28·5	·0017	26·4
26·6	·00062	9·2	..	..	..	..	..	..	30·2	·00096	14·4
27·3	·00062	9·3	..	..	..	..	..	..	32·7	·00065	9·8
33·8	·00053	7·9	..	..	..	..	..	..	34·6	·00086	13·0
32·7	·00046	6·8	..	..	..	..	..	..	35·2	·00074	11·0
		57·8									132·1
18·2	·00073	11·0	..	..	..	..	..	..	24·7	·0046	69·0
22·3	·00041	6·2	..	..	..	..	..	..	25·7	·0027	40·3
26·8	·00043	6·5	..	..	..	..	..	..	30·0	·0012	18·2
28·1	·00037	5·6	..	..	..	..	..	..	29·6	·0013	19·0
30·7	·00045	6·7	..	..	..	..	..	..	34·6	·00093	14·0
29·6	·00032	4·8	..	..	..	..	..	..	32·8	·00105	15·7
		40·8									176·2

Table

Period

Date	Depth	Uncropped Area								
		Uncultivated						Cultivated		
		Unmanured			Manured			Unmanured		
		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
1	2	3	4	5	6	7	8	9	10	11
22nd December 1926.	0—6	16·0	·0010	15·0	14·4	·00103	15·4	13·9	·00097	14·6
	6—12	27·1	·00059	8·8	22·2	·000472	7·1	25·3	·00058	8·7
	12—18	26·5	·00058	8·8	25·4	·000426	6·4	27·8	·00062	9·4
	18—24	34·7	·00060	9·0	28·6	·000378	5·7	30·7	·00051	7·7
	24—30	36·2	·00061	9·1	30·3	·000512	7·7	30·8	·00064	9·6
	30—36	33·1	·00059	8·8	33·3	·000458	6·9	31·4	·00064	9·7
				59·5			49·2			59·7
4th January 1927.	0—6	15·2	·00066	9·9	13·0	·000588	8·8	..	..	..
	6—12	25·0	·00036	5·4	26·2	·000369	5·5	..	..	..
	12—18	30·5	·00051	7·7	25·4	·000366	5·5	..	..	..
	18—24	30·8	·00032	4·8	30·3	·000384	5·8	..	..	..
	24—30	27·7	·00044	6·6	33·0	·000458	6·9	..	..	..
	30—36	28·0	·00025	3·7	36·6	·000405	6·1	..	..	..
				38·1			38·6			
6th January 1927.	0—6	10·0	·00114	17·2	10·0	·00104	15·6	10·8	·00110	16·5
	6—12	23·2	·00060	8·9	23·1	·000476	7·1	24·5	·00054	8·2
	12—18	26·2	·00043	6·4	24·4	·000542	8·1	24·6	·00048	7·3
	18—24	23·5	·00031	5·4	22·4	·00059	8·9	24·6	·00542	8·1
	24—30	25·2	·00048	7·3	24·0	·00048	7·2	27·5	·00056	8·4
	30—36	22·3	·00047	7·1	24·1	·00054	8·1	27·5	·00062	9·3
				52·3			55·0			57·8
				Tractor	*ploughed.*					
12th January 1927.	..	..	..	..	..	..	..	13·8	·00097	14·6
	..	..	..	..	..	..	..	23·3	·00053	8·0
	.	..	..	..	..	..	..	28·4	·00059	8·9
	..	..	..	..	..	..	..	30·4	·00044	6·7
	..	..	..	..	..	..	..	33·5	·00062	9·4
	..	..	..	..	..	..	..	31·8	·00052	7·8
										55·34

III—*contd.*

(*c*)—contd.

Cropped area											
Cultivated			Uncultivated after removal of crop						Uncropped, cultivated		
Manured			Unmanured			Manured			Unmanured		
% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
12	13	14	15	16	17	18	19	20	21	22	23
12·4	·00106	15·9	..	..	..	..	..	..	16·5	·00488	73·3
24·2	·00060	9·0	..	..	..	..	..	..	21·6	·00223	33·8
26·4	·00055	8·3	..	..	..	..	..	..	31·0	·00129	19·5
30·4	·00051	7·7	..	..	..	..	..	..	31·5	·00090	13·6
31·4	·00058	8·7	..	..	..	..	..	..	31·4	·00116	17·4
29·3	·00057	8·6	..	..	..	..	..	..	33·1	·00118	17·7
		58·2									175·1
..	..	..	12·3	·00018	7·2	16·3	·00039	5·8	..	..	..
..	..	..	23·6	·00030	4·5	26·0	·00037	5·5	..	..	..
..	..	..	22·9	·00042	6·2	26·5	·00030	4·6	..	..	..
..	..	..	27·5	·00031	4·7	[illegible]2·4	·00032	4·9	..	..	..
..	..	..	26·8	·00043	6·5	31·1	·00010	5·9	..	..	..
..	..	..	30·6	·00026	3·8	33·6	·00010	5·9	..	..	..
					32·9			32·6			
11·0	·00073	11·0	..	..	..	..	..	..	15·7	·00574	86·1
21·3	·00053	7·9	..	..	..	..	..	..	25·4	·00134	20·1
23·3	·00053	8·0	..	..	..	..	..	..	26·0	·00111	16·6
24·4	·00054	8·1	..	..	..	..	..	..	26·9	·00087	13·0
27·0	·00056	8·4	..	..	..	..	..	..	30·9	·00090	13·5
26·8	·00050	7·4	..	..	..	..	..	..	31·4	·00090	13·5
		50·8									162·8
					Tractor	*ploughed.*					
12·9	·00059	8·8	15·5	·00055	8·2	12·7	·00064	9·6	17·7	·00542	81·4
21·0	·00055	8·3	25·0	·00036	5·5	20·2	·00057	8·6	25·0	·0017	25·5
28·4	·00063	9·4	25·6	·00024	3·7	27·2	·00037	5·6	30·0	·00095	14·4
27·3	·00059	8·8	27·3	·00031	4·7	30·3	·00015	6·7	31·0	·00077	11·6
31·4	·00061	9·2	29·8	·00055	8·3	31·1	·00052	7·7	35·0	·00073	11·0
32·8	·00059	8·8	30·4	·00051	7·7	28·5	·00014	6·6	33·6	·00105	15·8
		53·3			38·1			44·8			159·7

13th November 1926 and 29th November 1926 the experiments were merely a continuation of the experiments in series (*a*) and no cultivated area was sampled on these two dates.

Throughout the period under experiment there was no rain except for a fall of 0·69″ on December 17th.

As regards the effect of cultivation on the original plots, it will be seen from the Table and Chart that the effect was practically negligible. All these plots contained very small amount of nitrates. There is some slight indication that cultivation had increased the nitrate in the surface soil, but it is doubtful if the difference observed lies outside the experimental error. As regards plot No. 7, referred to as plot No. III, uncropped unmanured cultivated, it will be seen that it contains large amounts of nitrates particularly in the surface 6″. It is unfortunate that analyses of this plot were only commenced on November 2nd. However, the soil of this field is apparently identical in every respect with the soil in the other plots under experiment. The only difference was in the cultivations carried out. It will be as well to compare the cultivation on this plot with that on the other 2 cultivated plots under observation in Series (*c*).

Cultivations on plots (3) and (4) *viz.* uncropped unmanured cultivated plots and uncropped manured cultivated plots.

August, September—*Nil.*
29th October—Ploughing.
31st October—Bakharing.
5th November—Clods broken by hand.
12th November—Clods broken by clod crusher.

Cultivations on plot No. 7 (Plot III) uncropped *unmanured* cultivated.

12th September—Tractor bakharing followed by spring tooth cultivator.
24th September—Tractor bakharing followed by spring tooth cultivator.
19th October—Bakharing.
22nd October—Harrowing.

There can be no doubt that the increased nitrate content of plot No. 7 is due to the more efficient cultivations it received as compared with plots (3) and (4).

Conclusion.

At the end of the rains, the black cotton soil of Nagpur contains only small amounts of nitrates. If the soil remains uncultivated throughout the cold weather no nitrate formation takes place. If, however, the soil is kept well cultivated at the end of the rains, large amounts of nitrates are formed in the surface soil and are available for the cold weather crops. By way of confirmation of this conclusion, we have available the results of analyses carried out in other plots which received efficient cultivations at the end of the rains.

Date	Depth	LB. NaNO$_3$ PER ACRE DRY SOIL		
		Near alkaline well	Students' well	Limed plot
1st November 1926	0 - 6	47·9	44·8	
	6 –12	22·4	15·1	
	12–18	11·5	13·5	
	18–24	11·8	9·8	
	24 - 30	9·9	15·9	
	30 - 36	11·6	13·9	
		115·1	113·0	
15th November 1926	0– 6	..	..	71·8
	6 –12	..	..	35·9
	12 –18	..	..	17·4
	18 - 24	..	..	13·8
	24 –30	..	..	12·2
	30 – 36	..	..	10·1
				161·2
0th January 1927	0– 6	77·8	71·9	
	6- 12	43·0	40·4	
	12—18	20·8	28·9	
	18—24	24·6	22·2	
	24–30	21·5	27·8	
	30–36	23·2	18·4	
		210·7	209·6	

It will be seen that the amounts of nitrate present in these soils is very high and ts formation must be due to the cultivations received at the end of the rains and in he early cold weather.

Summary and Recommendations.

. *The amount of nitrate produced in the soil and its bearing on the growth of crops in the Central Provinces.*

In the work described above, data have been given for the amount of nitrate resent in black cotton soil at Nagpur throughout the year. Plots both with and vithout crops were under experiment and the effect of cultivation after the rains n the nitrate content of the soil was also examined.

In the first place, it will be of interest to compare the amounts of nitrates found y us with those found by other workers in India, Egypt and England.

Our own results show that in April when the nitrate content of our soil is lowest, he soil throughout the top 3 feet examined contains on an average about 1 part f nitrate nitrogen per million of dry soil, or say 9 lb. of nitrate of soda per acre

in the top 6″ of soil. When nitrification has become well established after the break of the rains, the surface 6″ of soil frequently contains 5 or 6 parts per million and the second 6″ rather less. The maximum figure found by us was on June 21st, 1926, on a manured plot, the top 6″ of which contained nitrate nitrogen equal to 10 parts per million of dry soil and the second 6″ contained nitrate nitrogen equal to $3\frac{1}{2}$ parts per million.

At Pusa on the Gangetic alluvium, Leather obtained somewhat similar results to ours. He found that towards the end of the hot weather the surface soil contained about 1 part per million of nitrate nitrogen. After the first fall of rain this showed a rapid increase to $2\frac{1}{2}$ parts per million in the surface 6″ and to 12 parts per million in the second six inches.

At Cawnpore also in the Gangetic alluvium, Clarke and co-workers found 2·4 parts of nitrate nitrogen per million parts of dry soil in the top foot at the end of the rains, on September 14th. As a result of cultivation, this figure rose to 14·4 parts per million by the following March. Clarke did not continue his experiments during the rains.

Turning to work carried out by Prescott[1] in Egypt, we get figures of a very different order. Apparently in the hot dry weather the summer fallow land is very dry and then contains only 2·7 parts of nitrate nitrogen per million of dry soil. Yet this figure is far higher than we found in Indian soils in the dry hot weather. When we turn to the irrigated cotton soils of Egypt, however, we find that the amount of nitrate nitrogen is far higher than anything we ever experience in India. It rarely falls as low as 20 parts per million of dry soil and is usually between 30 and 40 parts and at times reaches 60 parts per million.

It may be of interest to mention figures obtained by Russell[2] at Rothamsted. The unmanured plot in the Broadbalk field was found to contain nitrate nitrogen varying in amount from 1 to 6 parts per million throughout the year. The figures for the dunged plot varied from 4 to 16 parts and for the double ammonia salts plot from 3 to 31 parts per million of dry soil.

It thus appears that under conditions prevailing on the black cotton soils of Central India, the amount of nitrification taking place during the growing period of the cotton crop is far smaller than that which takes place in Egypt during the cotton growing season. Under Egyptian conditions, the crop is grown in the hot weather under irrigation and thus both moisture and temperature conditions are favourable for nitrification. In Central India the crop is grown in the rainy season. When the first rains fall, rapid nitrification takes place, but the amount of nitrate produced never approaches the amounts of nitrate produced in Egyptian soils. Moreover, the crop is too small to take advantage of the nitrate produced at this early stage. Subsequent heavy falls of rain wash the nitrate out of the soil and if, as frequently happens in India, rain falls more or less continuously for weeks on end the cotton

[1] *Jour. Agri. Sci.*, Vol. IX, 1919, p. 216.
[2] *Jour. Agri. Sci.*, Vol. VI, 1914, p. 28.

crop suffers from nitrogen starvation. In Egypt the regular irrigations keep up a large store of nitrates in the soil and Prescott[1] states that "The cotton crop in Egypt at the present time is indeed independent of the artificial application of fertilisers." It is not surprising that the cotton outturns in Central India compare so unfavourably with those of Egypt. This matter could be remedied to some extent by the judicious use of nitrogenous fertilisers. At the same time great skill is necessary in order that these should be applied at the right time. One wants to put them on after a heavy fall of rain, but if further heavy rain falls subsequent to the application of the fertiliser it is simply washed down into the soil out of reach of the crop.

One is almost inevitably drawn to the conclusion that cotton is hardly the crop to grow in the Berars. Certainly, its area is far too large. During recent years the high prices obtained have encouraged the growing of a large area of this crop. The indications are that the prices realisable in future will be on the pre war scale, yet the costs of production are hardly likely to go back to that level. Our results indicate that soil conditions are such that we can never hope to compete on a yield basis with Egypt and other centres where irrigation facilities are available. Therefore, it would seem that there should be an extension of the growth of *juari* and fodder and that some of the area now growing cotton would be better so employed. The improvement in the supply of fodder would improve the cattle by better feeding and with the provision of better cattle, agricultural operations would become more efficient, better crops could be obtained and the milk supply of the country could also be improved.

Groundnut in certain areas should prove an excellent substitute for cotton. Our results also indicate that efficient cultivation at the close of the rains encourages the production of quite a large store of nitrates in the soil and hence the possibility of extending the area of cold weather crops is worth investigation. Mr. Allan has dealt with the question of substitutes for cotton and with the extension of the *rabi* area in a note at the end of the Memoir.

II. The loss of nitrate from the soil.

The foregoing work has provided some indications of the enormous loss of nitrate which takes place from the black cotton soil of Central India during the rains.

Thus during the rains of 1925 a loss of nitrate nitrogen equivalent to 480 and 626 lb. of nitrate of soda per acre respectively was observed on an unmanured and manured plot cropped with cotton.

In the succeeding season the same plots cropped with *juar* lost respectively nitrate nitrogen equivalent to 268 and 374 lb. of nitrate of soda per acre. Similar uncropped plots lost nitrate nitrogen equivalent to 229 and 374 lb. of nitrate of soda per acre respectively. It must be remembered that these manured plots received during these periods of loss a top dressing of nitrate of soda equal to 65 lb. per acre.

[1] *Loc. cit.*, p. 218.

The method by which these losses have been estimated is essentially rough, but the results are undoubtedly on the low side. When we come to consider the results of our well water studies in Part III of this paper, it will be seen that the actual losses of nitrate nitrogen from our soil during the rains must be much greater than these figures indicate.

Table IV.

Experimental error in nitrate estimation.

As stated on page 159 each determination of nitrate in the soil was carried out on a composite sample made up by mixing four individual cores. Occasionally, however, these cores were analysed separately for moisture and nitrate content and certain of these determinations are set out below.

Depth	No. of core	Uncropped Area				Cropped Area			
		Unmanured		Manured		Unmanured		Manured	
		Sampled on 1-9-26		Sampled on 26-8-26		Sampled on 13-9-26		Sampled on 16-8-26	
		% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil	% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil	% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil	% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil
0—6″	1	34·3	11·9	33·9	14·9	35·3	8·0	44·6	18·5
	2	39·1	14·3	37·0	14·3	32·9	5·9	40·0	20·9
	3	36·6	14·2	34·9	12·0	31·1	5·8	41·5	19·1
	4	36·3	14·2	35·0	15·0	31·2	6·0	40·9	19·0
6—12″	1	34·3	11·9	34·6	13·9	31·1	7·9	39·3	15·6
	2	34·9	12·0	33·1	13·7	31·8	5·8	38·0	24·7
	3	33·8	11·9	34·3	11·9	31·0	5·8	38·9	15·5
	4	33·6	13·8	32·8	13·7	33·0	5·9	37·2	17·4
12—18″	1	37·0	10·2	37·9	10·3	34·6	5·8	35·5	11·1
	2	35·3	12·1	33·4	11·8	34·0	4·9	38·2	14·4
	3	37·0	12·2	36·5	10·2	32·6	4·0	38·4	13·4
	4	39·1	12·5	35·3	10·0	33·8	6·1	37·1	15·2
18—24″	1	39·3	11·4	39·1	10·4	36·7	5·0	36·8	11·2
	2	40·5	11·6	36·5	12·2	33·2	4·9	39·2	12·5
	3	38·7	11·4	41·8	10·6	33·0	4·5	38·4	14·5
	4	40·0	12·6	38·7	10·4	35·1	6·3	38·8	15·5
24—30″	1	36·3	22·3	[illegible]	21·0	39·9	1·0	37·0	24·5
	2	39·8	18·8	38·7	20·7	34·9	5·0	36·2	14·2
	3	41·1	15·9	39·7	16·7	35·3	4·1	36·7	13·2
	4	40·5	16·9	42·6	19·3	36·9	5·2	37·6	19·5
30—36″	1	38·6	25·2	38·6	20·7	38·8	3·9	36·4	17·2
	2	41·1	23·3	37·8	18·5	34·7	7·2	40·0	14·7
	3	43·6	19·4	39·0	16·6	38·4	4·0	39·9	14·6
	4	41·6	19·1	39·2	25·0	35·8		35·3	24·1

Table V.

Rainfall, 1925.

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	..	..	..	..	..	..	0·12	..	0·14	..	..	..
2	..	..	..	..	..	..	..	0·14	0·63	..	..	..
3	..	..	..	..	0·04	..	..	..	0·27	..	..	..
4	..	..	..	..	..	..	..	..	..	..	..	..
5	..	..	..	..	..	..	..	0·24	..	..	..	..
6	..	..	..	..	..	..	0·11	0·26	..	..	..	..
7	..	..	..	..	..	0·05	1·31	0·64	..	..	..	..
8	..		..	..	..	..	0·13	0·11	0·20	..	..	..
9	..	..	..	..	0·17	..	0·80	..	..	..	..	..
10	..	..	..	..	0·38	..	2·57	5·63	..	..	1·60	..
11	..	..	..	..	..	..	0·39	0·33	..	..	0·15	..
12	..	..	..	..	..	0·30	0·14	0·28	..	..	0·45	..
13	..	..	0·23	..	..	0·78	1·38	..	..	..	0·12	..
14	..	..	..	..	..	..	0·02	..	..	..	..	..
15	..	..	..	..	..	..	0·14	..	0·25	1·58	..	..
16	..	..	..	..	..	..	..	5·13	0·16	..	..	..
17	..	..	..	..	..	0·62	0·33	1·20	..	..	..	..
18	..	..	..	..	..	..	0·79	2·27	..	..	..	..
19	..	..	..	..	0·12	0·64	0·10	0·73	..	..	..	..
20	..	..	..	..	..	0·59	0·04	..	..	0·15	..	..
21	..	..	..	..	..	1·29	0·26	0·38	1·06	..	0·64	..
22	..	..	..	..	..	0·26	0·03	..	..	..	0·32	..
23	..	..	..	..	..	1·90	0·52	1·82	..	..	..	..
24	..	..	..	..	..	0·03	0·25	0·55	..	..	..	..
25	..	..	..	..	..	..	..	0·32	..	..	..	..
26	..	..	..	..	..	0·45	0·07	0·28	..	..	..	..
27	..	..	..	..	0·04	0·44	0·21	0·38	0·63	..	..	..
28	..	..	..	..	..	..	0·14	..	..	0·55	..	..
29	..	..	..	..	0·11	0·48	0·90	..	0·12	..	..	..
30	..	..	..	..	..	1·48	4·05	0·70	..	..	..	0·08
31	..	..	..	..	0·69	..	0·10	1·71	..	..	..	..
Total .	..	..	0·23	..	1·55	9·31	15·50	23·43	3·76	2·28	3·28	0·08
Total for year .	..	..	0·23	..	1·78	10·09	25·59	49·02	52·78	55·06	58·34	58·12

TABLE V.

Rainfall, 1926.

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	..	..	..	0·03	0·17	..	0·25	0·07	0·09	..	..	..
				0·02								
2	0·01	..	..	..	..	..	0·09	0·01	0·05	..	..	..
3	0·67	..	..	..	..	..	0·28	0·27	0·19	1·21	..	..
4	0·46	..	..	..	..	0·06	1·60	1·64	0·04	0·05	..	..
5	0·02	..	..	..	..	..	4·85	1·12	0·57	0·02	..	..
6	..	..	..	0·22	..	..	0·67	0·05	..	0·28	..	..
7	..	..	0·19	0·22	0·18	..	..	0·59	0·13	0·03	..	..
8	0·01	..	0·50	0·02	0·21	..	4·11	1·69	..	0·13	..	..
9	0·50	..	..	0·05	..	..	0·33	0·85	..	0·33	..	..
10	..	..	..	..	0·26	..	0·41	0·47	1·97	..	..	..
11	..	..	..	..	0·12	..	1·60	0·89	0·02	..	..	..
12	..	..	..	..	0·11	..	3·11	0·29	..	..	..	..
13	..	..	..	..	..	..	1·17	0·07	0·03	..	..	..
14	..	..	..	..	..	..	0·26	0·07	0·16	..	..	..
15	..	..	0·41	..	..	..	0·23	0·02	0·03	..	..	..
16	..	..	..	..	..	0·03	0·38	0·91	..	..	..	..
17	..	..	..	..	..	..	..	0·94	..	..	..	..
18	..	..	..	..	2·18	..	0·05	2·13	..	..	..	..
19	..	..	..	..	1·06	..	..	0·73	0·23	..	..	..
20	..	..	..	..	1·14	0·07	..	0·21	0·11	..	..	..
21	..	..	..	..	..	0·15	..	0·64	..	..	..	..
22	..	..	..	..	0·75	0·11	..	0·59	..	..	..	..
23	..	..	0·02	..	..	0·02	..	0·01	..	..	..	..
24	..	..	0·37	..	..	..	0·05	0·03	..	..	..	..
25	..	..	..	..	..	..	0·08	..	..	..	..	..
26	..	..	..	..	..	..	..	..	..	..	..	..
27	..	..	..	..	..	..	0·19	2·10	0·01	..	..	..
28	..	..	..	..	..	0·14	0·27	0·21	..	..	..	..
29	..	..	..	..	..	..	..	0·01	..	..	..	..
30	0·36	..	..	..	..	..	..	0·29	..	..	..	..
31	..	..	0·17	..	..	..	..	0·11	..	..	..	..
Total .	2·05	..	1·66	0·56	6·18	0·58	20·86	17·07	3·63	2·05	..	..
Total for year .	2·09	..	3·75	4·31	10·79	11·37	32·23	49·30	52·93	54·98	54·98	54·98

PART II.

SEASONAL COMPOSITION OF WELL WATERS AS A MEANS OF STUDY OF THE NITROGEN CYCLE IN THE SOIL.

In Part I of this paper attention has been drawn to the large amounts of nitrates formed in the soil during the early part of the rainy season at Nagpur. It was also shown that most of this nitrate was washed out of the soil into the drains or into the underground water supply by heavy rain. Losses of nitrate nitrogen equal to several hundreds of pounds of nitrate of soda per acre at least were indicated.

It would appear of great interest to see what happens to the nitrate which is washed out of the surface soil. This matter has not received much attention hitherto. It is frequently stated that practically no denitrification takes place in soils. If this nitrate is accumulated in the subsoil water one would expect to find enormous stores of nitrate down below. Large accumulations of nitrates in the soil are, however, rare, the best known example being, of course, the Chilean nitrate deposits. But the conditions under which these deposits have accumulated are peculiar and are seldom met with.

It was considered that a study of the levels and chemical composition of the water in wells throughout the year should give results of interest in this connection. An intimate study of two wells on the Agricultural College Farm, Nagpur, was commenced in June 1925. The investigation has been carried on continuously since that date. The wells are about 200 yards apart and are sunk in the black cotton soil. One we have called " Students' well " and the other " Alkaline well ". The former is 627″ from soil level to the bottom and the latter only 507″ and both just reach the trap rock. The former has not been used for many years and has a tile drain discharging into it and thus we were able to form an idea of the rate of nitrification in the surrounding soil. The latter well is used to a certain extent for irrigation and the land around has received heavy dressings of cattle manure and artificials for some years. Moreover, the area surrounding this well is also underdrained with tile drains and hence we are able to analyse the drainage water from this area also. The depth of water was determined at frequent intervals and always when any change in water level took place. On every such occasion, the water was analysed for total solids, nitrate content and usually for bicarbonates and carbonates and occasionally gravimetric estimations were made of the calcium, magnesium and sulphate contents. It was quite early recognised that the composition of the water was not always uniform at different levels and soon after the experiment started each well was always sampled at 3 different levels, bottom, middle and top. These samples were taken in a weighted bottle, the stopper of which could be opened by a string at any desired level.

The nitrate was determined by the phenoldisulphonic acid method as in Part I.

Tables VI and VII give the data obtained for well levels, total solids and nitrate content of the two wells under observation.

From August 1925 onwards, the samples were drawn from 3 different levels, bottom, middle and top. The bracketed figures give the analyses in this order.

The rainfall during the period under observation has already been given in part I of this paper. The rainfall data, well levels and nitrate content of the wells have been plotted in Chart No. III.

Consideration and discussion of results.

I. General observations on well levels and nitrate content.

At the beginning of the rains in June 1925, the students' well had a depth of 400″ of water and the alkaline well of 280″.

Table VI.

Students' well.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
1	22nd June 1925	238″	69·5	0·010	0·22
2	29th " "	238″	68·8	0·024	0·50
3	7th July "	238″	68·4	0·020	0·42
4	13th " "	172″	60·2	0·072	1·76
5	15th " "	166″	50·3	0·080	1·98
6	20th " "	165½″	45·8	0·088	2·16
7	27th " "	162″	51·4	0·095	2·35
8	3rd August "	139″	45·6	0·110	2·85
9	10th " "	106″	49·1	0·13	3·60
10	17th " "	76″	45·8	0·13	3·80
11	28th " "	49″	64·2 56·5 45·8	0·00 0·05 0·09	1·53
2	31st " "	43″	63·3 60·6 46·8	0·02 0·01 0·09	1·24

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
13	7th September 1925 . . .	48″	62·1 58·0 46·4	0·02 0·03 0·03	0·83
14	15th „ „ . . .	69″	58·8 68·5 48·9	0·02 0·05 0·05	1·23
15	21st „ „ . . .	80″	56·2 60·0 48·1	0·02 0·02 0·03	0·72
16	28th „ „ . . .	87″	62·6 56·9 47·7	0·02 0·02 0·02	0·66
17	5th October „ . . .	95″	63·2 56·2 48·1	0·03 0·03 0·03	0·85
18	12th „ „ . . .	102″	62·32 56·24 49·36	0·01 0·01 0·01	0·37
19	19th „ „ . . .	108″	61·28 53·20 50·56	0·02 0·01 0·01	0·39
20	26th „ „ . . .	116″	54·40 55·60 55·60	0·02 0·02 0·01	0·43
21	2nd November „ . . .	121″	55·92 54·80 55·52	0·01 0·01 0·01	0·47
22	9th „ „ . . .	126″	55·20 54·64 54·16	0·01 0·01 0·01	0·31
23	17th „ „ . . .	130″	52·08 54·80 54·32	0·01 0·01 0·01	0·40
24	23rd „ „ . . .	131″	54·32 55·20 54·16	0·01 0·01 0·01	0·40
25	30th „ „ . . .	134″	56·48 54·96 55·44	0·02 0·02 0·02	0·59

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
26	7th December 1925 . . .	139″	60·48 62·96 58·40	0·02 0·02 0·02	0·052
27	14th " " . . .	141″	55·28 55·28 54·80	0·03 0·02 0·02	0·071
28	21st " " . . .	145″	55·44 54·80 53·60	0·02 0·01 0·01	0·047
29	28th " " . . .	148″	56·40 55·76 56·00	0·02 0·02 0·02	0·57
30	5th January 1926 . . .	149″	55·60 57·76 52·08	0·02 0·02 0·02	0·051
31	11th " " . . .	153″	54·80 54·80 54·72	0·02 0·02 0·02	0·05
32	18th " " . . .	154″	56·48 55·60 54·80	0·03 0·02 0·02	0·067
33	25th " " . . .	160″	57·04 55·84 55·20	0·01 0·01 0·01	0·415
34	1st February " . . .	163″	57·60 56·08 57·36	0·02 0·02 0·02	0·64
35	10th " " . . .	168″	55·44 55·20 55·84	0·01 0·01 0·01	0·43
36	15th " " . . .	170″	55·28 55·68 56·00	0·02 0·02 0·02	0·61
37	22nd " " . . .	173″	54·80 54·64 55·20	0·02 0·02 0·02	0·558
38	1st March " . . .	176″	55·84 55·52 56·00	0·02 0·02 0·02	0·46

Table VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
39	10th March 1926	180″	56·56 56·72 56·08	0·12 0·12 0·02	0·47
40	15th ,, ,, ...	182″	56·88 56·80 57·76	0·01 0·01 0·01	0·39
41	24th ,, ,, ...	186″	57·60 56·96 56·96	0·02 0·02 0·02	0·55
42	29th ,, ,, ...	188″	57·04 57·20 56·88	0·01 0·01 0·01	0·39
43	6th April ,, ...	192″	58·24 58·08 57·76	0·01 0·01 0·01	0·37
44	12th ,, ,, ...	194″	57·44 56·08 58·96	0·01 0·01 0·01	0·35
45	19th ,, ,, ...	197″	57·12 57·92 57·52	0·01 0·01 0·01	0·34
46	24th ,, ,, ...	201″	57·76 58·24 58·00	0·01 0·01 0·01	0·34
47	3rd May ,, ...	204″	58·72 60·80 59·76	0·007 0·007 0·010	0·19
48	10th ,, ,, ...	206″	58·16 57·92 58·88	0·01 0·01 0·01	0·22
49	17th ,, ,, ...	208″	58·00 57·68 59·52	0·00 0·00 0·00	0·00
50	19th ,, ,, ...	208″	58·48 57·68 59·28	*Nil*	*Nil*
51	28th ,, ,, ...	210″	58·24 58·38 58·96	,,	,,

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
52	2nd June 1926 . . .	212″	58·08 56·00 59·60	*Nil*	*Nil*
53	8th " " . . .	215″	59·36 59·76 61·60	"	"
54	16th " " . . .	217″	60·16 60·22 62·40	"	"
55	23rd " " . . .	218″	61·12 60·56 61·52	"	"
56	29th " " . . .	220″	61·52 61·52 62·96	"	"
57	6th July " . . .	212″	61·60 60·56 59·36	"	"
58	12th " " . . .	187″	58·64 57·84 50·08	0·11	0·82
59	26th " " . . .	162″	63·28 57·92 47·84	0·00 0·00 0·09	0·74
60	3rd August " . . .	149″	58·00 57·28 46·00	0·01 0·01 0·04	0·64
61	10th " " . . .	109″	50·80 48·08 40·00	0·07 0·09 0·02	0·30
62	17th " " . . .	84″	51·12 49·28 41·60	0·06 0·09 0·15	2·94
63	25th " " . . .	60″	49·44 47·84 43·60	0·08 0·08 0·10	2·61
64	3rd September " . . .	51″	55·60 47·68 43·20	0·04 0·07 0·10	2·23

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Nitrate N as N	Total lb. of $NaNO_3$ in well
65	9th September 1926	58″	48·32 45·04 43·44	0·04 0·05 0·04	1·29
66	15th " "	60″	46·32 47·92 43·28	0·03 0·02 0·02	0·81
67	21st " "	68″	47·76 50·08 45·12	0·04 0·04 0·06	1·51
68	1st October "	84″	47·36 48·08 45·12	0·04 0·04 0·05	1·38
69	9th " "	84″	51·52 50·48 44·64	0·02 0·02 0·03	0·75
70	15th " "	97″	53·52 47·68 47·52	0·02 0·04 0·04	0·96
71	23rd " "	99″	50·72 55·28 51·04	0·005 0·005 0·005	0·14
72	29th " "	108″	50·72 51·28 51·04	*Nil*	*Nil*
73	3rd November "	109″	51·36 50·88 50·80	"	"
74	13th " "	118″	50·48 51·52 50·40	0·012 0·017 0·020	0·44
75	20th " "	124″	51·60 52·00 51·12	0·02 0·017 0·017	0·39
76	26th " "	128″	51·60 50·56 50·96	0·017 0·015 0·015	0·42
77	4th December "	133″	51·44 52·96 50·72	0·012 0·012 0·012	0·32

TABLE VI—*concld.*

Students' well—concld.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
78	11th December 1926 . . .	141″	52·24 51·36 51·36	0·012 0·012 0·012	0·32
79	18th " " . . .	140″	51·68 51·76 50·88	0·012 0·012 0·012	0·28
80	24th " " . . .	144″	54·00 55·36 55·12	0·012 0·007 0·005	0·21

TABLE VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
1	22nd June 1925 . . .	224″	77·6	0·22	3·52
2	29th " " . . .	224″	77·8	0·14	2·26
3	13th July " . . .	193″	76·0	0·12	2·09
4	15th " " . . .	178″	74·9	0·10	1·90
5	20th " " . . .	144″	75·6	0·08	1·61
6	27th " " . . .	128½″	76·0	0·22	4·60
7	3rd August " . . .	93½″	74·40 74·24 74·40	0·21 0·21 0·20	4·80
8	10th " " . . .	66½″	68·40	0·19	4·63
9	17th " " . . .	62″	65·52	0·19	4·68
10	19th " " . . .	56″	75·44 73·76 66·32 65·44 63·20 63·60	0·17 0·17 0·17 0·17 0·17 0·17	4·24

TABLE VII—*contd.*

Alkaline well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
11	21st August 1925	60″	74·80 72·24 64·64	0·14 0·18 0·16	3·96
12	24th ,, ,, ...	50″	70·56 68·68 68·04	0·12 0·12 0·12	3·03
13	31st ,, ,, ...	57″	69·12 68·56 65·44	0·11 0·11 0·10	2·66
14	7th September ,, ...	66′	68·56 68·88 68·16	0·12 0·12 0·10	2·76
15	15th ,, ,, ...	88′	68·96 50·80 69·16	0·03 0·05 0·10	1·39
16	21st ,, ,, ...	91″	68·96 66·40 66·00	0·03 0·06 0·01	0·75
17	28th ,, ,, ...	87″	69·28 67·52 66·24	0·05 0·03 0·08	1·23
18	5th October ,, ...	98″	67·84 67·60 67·28	0·04 0·06 0·07	1·29
19	12th ,, ,, ...	107′	69·12 61·12 69·24	0·017 0·02 0·02	0·48
20	19th ,, ,, ...	107″	80·00 58·24 67·04	0·032 0·030 0·030	0·68
21	26th ,, ,, ...	137″	74·16 70·64 73·04	0·15 0·15 0·15	3·12
22	2nd November ,, ...	153″	74·72 73·76 72·72	0·10 0·10 0·10	2·05
23	9th ,, ,, ...	154″	74·56 75·04 75·04	0·22 0·21 0·22	4·23

TABLE VII—*contd.*

Alkaline well—contd.

S No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
24	17th November 1925 . . .	129″	74·22 74·96 73·04	0·22 0·22 0·23	4·66
25	23rd " " . . .	123″	75·36 74·48 75·52	0·22 0·22 0·24	4·73
26	30th " " . . .	159″	76·32 75·84 77·28	0·26 0·26 0·26	5·00
27	7th December " . . .	159″	87·44 76·16 72·08	0·32 0·31 0·30	5·96
28	14th " " . . .	149″	76·08 76·56 76·72	0·36 0·34 0·34	6·86
29	21st " " . . .	155″	65·28 70·00 73·60	0·30 0·32 0·32	6·08
30	28th " " . . .	149″	76·92 75·04 72·80	0·32 0·30 0·30	6·07
31	5th January 1926 . . .	151″	83·44 68·56 75·04	0·36 0·40 0·40	7·65
32	11th " " . . .	153″	75·68 69·44 74·88	0·34 0·34 0·32	6·45
33	18th " " . . .	154″	75·92 77·92 75·60	0·44 0·42 0·42	8·33
34	25th " " . . .	167″	74·40 76·80 78·24	0·30 0·44 0·44	7·38
35	1st February " . . .	163″	76·80 76·08 76·24	0·42 0·42 0·42	7·98
36	10th " " . . .	167″	75·68 75·36 75·92	0·34 0·32 0·32	6·13

Table VII.

Alkaline well.

No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
37	15th February 1926 . .	185″	75·36 75·56 77·52	0·44 0·44 0·44	7·82
38	22nd ,, ,, ...	172″	75·68 75·81 77·80	0·42 0·42 0·42	7·76
39	1st March ,, ...	182″	76·32 76·96 77·20	0·40 0·40 0·40	7·17
40	10th ,, ,, ...	185″	76·24 76·32 76·32	0·34 0·34 0·36	6·16
41	15th ,, ,, ...	190″	77·44 77·44 78·16	0·32 0·32 0·32	5·59
42	23rd ,, ,, ...	185″	77·20 75·20 76·80	0·28 0·30 0·30	4·62
43	29th ,, ,, ...	208″	77·44 77·12 78·00	0·22 0·24 0·24	3·84
44	6th April ,, ...	204″	77·52 78·32 78·64	0·24 0·28 0·28	4·12
45	12th ,, ,, ...	193″	79·12 79·04 80·96	0·22 0·24 0·24	4·03
46	19th ,, ,, ...	197″	77·44 76·96 78·32	0·18 0·20 0·20	3·30
47	24th ,, ,, ...	208″	77·12 77·12 77·36	0·28 0·28 0·28	4·61
48	3rd May ,, ...	207″	78·24 78·24 77·68	0·24 0·24 0·24	3·97
49	10th ,, ,, ...	206″	77·04 77·04 76·88	0·24 0·24 0·24	3·98

TABLE VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb of $NaNO_3$ in well
			Total solids	Nitrate N as N	
50	17th May 1926 . . .	248″	76·72 76·16 76·24	0·24 0·28 0·28	3·80
51	19th „ „	220″	75·28 74·96 75·28	0·32 0·32 0·32	5·06
52	28th „ „ . .	222″	77·12 75·92 76·00	0·26 0·30 0·30	4·50
53	2nd June „ . . .	225″	74·88 74·00 75·46	0·24 0·30 0·30	4·35
54	8th „ „ . . .	215″	75·68 74·24 75·92	0·22 0·29 0·29	4·30
55	16th „ „ . . .	240″	76·40 73·28 75·28	0·34 0·36 0·34	5·09
56	23rd „ „ . . .	268″	77·74 76·08 74·96	0·26 0·34 0·34	4·13
57	29th „ „ . . .	255″	77·04 75·20 71·64	0·32 0·46 0·46	5·74
58	6th July „ . . .	216″	74·24 72·88 72·32	0·44 0·44 0·44	7·06
59	13th „ . . .	151″	73·52 72·80 71·68	0·44 0·44 0·44	8·65
60	26th „ „ . . .	117″	74·40 75·44 75·32	0·34 0·36 0·40	7·91
61	3rd August „ . . .	123″	74·96 72·88 72·40	0·30 0·40 0·40	7·79
62	10th „	69″	72·40 71·44 70·00	0·42 0·48 0·44	10·83

Table VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
63	17th August 1926	60″	71·36 69·92 71·00	0·40 0·39 0·39	9·72
64	25th ,, ,, ...	62½″	69·60 68·88 68·40	0·28 0·28 0·28	6·88
65	3rd September ,, . .	60″	68·96 67·20 65·92	0·24 0·24 0·24	5·94
66	9th ,, ,, ...	65″	68·40 70·80 69·52	0·29 0·29 0·29	7·09
67	15th ,, ,, ...	65″	66·64 66·72 65·92	0·22 0·22 0·22	5·38
68	21st ,, ,, ...	76″	66·96 65·12 66·08	0·20 0·20 0·20	4·77
69	1st October ,, ...	103″	71·36 69·20 68·32	0·19 0·19 0·19	4·21
70	9th ,, ,, ...	90″	71·84 68·64 68·48	0·14 0·14 0·14	3·23
71	15th ,, ,, ...	95″	71·52 69·28 69·04	0·11 0·15 0·12	3·12
72	23rd ,, ,, ...	117″	70·22 71·28 69·44	0·13 0·13 0·13	2·50
73	29th ,, ,, ...	177″	73·52 75·20 75·44	0·24 0·22 0·20	4·01
74	3rd November ,, ...	157″	73·52 73·68 73·60	0·30 0·30 0·30	5·80
75	13th ,, ,, ...	143′	73·44 75·68 76·24	0·32 0·32 0·32	6·43

Table VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
76	20th November 1926	137″	75·04 74·72 74·56	0·36 0·34 0·34	7·09
77	26th „ „	157″	76·00 76·72 75·28	0·38 0·36 0·36	7·09
78	4th December „	151″	75·6 74·32 75·04	0·34 0·34 0·34	6·60
79	11th „ „	155″	76·0 76·96 75·6	0·34 0·34 0·34	6·61
80	18th „ „	153″	75·14 74·96 74·96	0·40 0·40 0·40	7·82
81	24th „ „	161″	76·08 75·6 74·32	0·36 0·36 0·40	7·13

The former contained practically no nitrate, *viz.*, nitrate ·0105 parts nitrogen per 100,000 or 0·218 lb. $NaNO_3$ in the whole well. The latter well was fairly rich in nitrate, *viz.*, 0·226 parts of nitrogen per 100,000 or 3·52 lb. $NaNO_3$ in the whole well. With the first rapid rise of both wells about the 7th July, the former increased in nitrate content and the latter lost nitrate and by mid July the total nitrate content was about equal in the two wells. The nitrate content then increased in both. In the case of the Alkaline well, it rose almost to its highest point abruptly at the end of July when it contained 4·6 lb. $NaNO_3$ in the whole well. It remained constant at about this level of nitrate content till mid August. The Students' well showed a gradual rise in nitrate content and reached its maximum content of 3·8 lb. $NaNO_3$ just after mid August. The more abrupt rise in nitrate content of the Alkaline well was accompanied by a more abrupt rise in the well level than occurred in the case of the Students' well. It is probable that this difference in rapidity of rise between the two wells is due to the fact that the soil surrounding the Alkaline well was irrigated during the dry weather. Water would percolate more rapidly through this moist soil than it would through the drier unirrigated soil surrounding the Students' well.

Both wells reached their highest water level in the last week of August, but from the 3rd week of August a steady fall in nitrate content began and each well contained only about $\frac{1}{2}$ lb. $NaNO_3$ by mid October. The levels of both wells began falling steadily from the beginning of September. The Students' well never again recovered its nitrate content and in May 1926 it contained not a trace of nitrate. At the end of October, however, the nitrate content of the Alkaline well began to rise steadily and throughout the cold weather 1925-26 it contained more nitrate than at any time during the preceding rains. Early in November it contained 4·2 lb. of $NaNO_3$ or nitrate nitrogen =·22 parts of nitrogen per 100,000, and on January 1st, 1926 it contained 8·33 lb. of $NaNO_3$ or nitrate =·44 parts of nitrogen per 100,000. The rise in nitrate content of this well in the cold weather must be ascribed to the fact that it was used for irrigation of the surrounding land during that period. This irrigation water circulated through the soil back to the well. Rapid nitrification took place on this moist soil and the excess nitrates were, of course, washed back into the well. That there were large accumulations of nitrate in the cold weather of 1925-26 was proved by the fact that there was a sudden flow of the tile drains in this area on November 9th, following a $1\frac{1}{2}''$ fall of rain and this drainage water was exceedingly rich in nitrate. The results obtained from these two wells in 1926 were similar to those of the previous year. The rise of well level early in the rains was again more abrupt in the case of the Alkaline well than in that of the Students' well. It is remarkable, however, that during the rains of 1926 the Alkaline well was much richer in nitrate than during the previous rainy season. Thus in the rains of 1926 it reached the maximum $NaNO_3$ content of 10·8 lb. and from 6th July to 25th August never fell below 7 lb. of $NaNO_3$, whereas during the rains of 1925 it only contained a maximum of 4·6 lb. The Students' well, however, reached a maximum content of only 3·3 lb. during the rains of 1926 as against 3·8 lb. in the previous rainy season and generally appeared to contain less nitrate throughout the rainy season of 1926 than in 1925. Moreover, in 1926 it had lost all its nitrate by the end of October, whereas in the previous season it contained small amounts of nitrate throughout the cold weather and up to May 1926. Small amounts of nitrate were, however, found in this well subsequent to October 1926. It is difficult to find a reason for the difference in behaviour of these two wells in two succeeding seasons. To a certain extent, the year 1926 was exceptional in that there was a fall of about 6″ of rain in the 3rd week of May. This may have encouraged nitrification on the highly manured soil around the alkaline well to a greater extent than on the unmanured soil round the Students' well.

Before leaving this question of well levels, it will be of interest to draw attention to the fluctuations which occur in the level of the Alkaline well as compared with the level of the Students' well. This is well seen in the Chart and it is only necessary to remark that the fluctuations in level corresponded to the periods during which the Alkaline well was being used for irrigation.

2. Losses of nitrate from the well water.

It will be obvious from the Table and Chart that the nitrate which passes into the well water gradually disappears. The Students' well contained a maximum amount of 3·8 lb. of $NaNO_3$ in the rains of 1925. By May 1926 this had completely disappeared. The surface area of this well is 17·72 square yards. The loss of nitrate of soda per acre per year in the underground soil water which occurred on the unmanured area surrounding the Students' well may thus be taken to be 4840/17·72×3·8 or 1038 lb. In the rains of 1926 the loss observed was 3·3 lb. of $NaNO_3$ =4840/17·72×3·3 or 901 lb. $NaNO_3$ per acre. In the case of the manured land surrounding the Alkaline well, the losses would appear to be far greater. Thus on 3rd August 1925 this well contained 4·8 lb. of $NaNO_3$ and on 12th October it only contained 0·48 lb. of $NaNO_3$ a loss of 4·32 lb. of $NaNO_3$. The surface area of this well is 19 square yards, hence the loss per acre in 1925 was 4840/19×4·32 or 1100 lb. of $NaNO_3$. Figures for the early part of the year 1925 are not available. On the 18th January 1926 this well again contained 8·33 lb. of $NaNO_3$ and on 19th April this amount had fallen to 3·3 lb. a loss of 5 lb. $NaNO_3$ =4840/19×5 or 1274 lb. $NaNO_3$ per acre. On 10th August 1926 this well again contained 10·83 lb. $NaNO_3$ and by 23rd October this figure had fallen to 2·80 a loss of 8 lb. $NaNO_3$ = 4840/19×8 or 2037 lb. $NaNO_3$ per acre.

It thus appears that the unmanured unirrigated soil surrounding the Students' well annually loses nitrate equivalent to about 1000 lb. nitrate of soda per acre or say 165 lb. nitrogen. The irrigated highly manured soil surrounding the Alkaline well lost during the year 1926 nitrate equivalent to 1274+2037 =3311 lb. of $NaNO_3$ per acre or say 550 lb. of nitrogen. In making these calculations, we have assumed that the water table is a continuation of the well level throughout the subsoil and that the whole of this subsoil water suffers losses similar to those of the well water. This we consider a reasonable assumption. If it were not the case, one would not expect the *complete* disappearance of nitrate from the well and absence of nitrate for 6-7 weeks or more as we found in the case of the Students' well in May and June 1925 and again from the end of October 1926 to date of writing (January 1927). If the rest of the underground water contained nitrate, it would surely diffuse to some extent into the well.

These losses are enormously greater than have been observed elsewhere. Thus in the Broadbalk[1] field at Rothamsted the largest loss of nitrate nitrogen from any of the plots is computed to be about 78 lb. annually. This was from a plot receiving minerals +400 lb. ammonium salts. The unmanured plot was computed to have lost less than 18 lb. nitrate nitrogen. However, these figures are but a rough estimate since the amount of water passing into the subsoil was not accurately measured but was in part computed from the flow through the drain gauges. Batham[2] in work on the drain gauges at Cawnpore found an average annual loss from

[1] The Book of the Rothamsted Experiments, Hall & Russell, p. 235, 1919.
[2] *Mem. Dept. Agri. India, Chem. Ser.*, VIII, No. 8, p. 138, 1926.

the 6-foot drain gauge during 1905-09 of 81 lb. nitric nitrogen per acre. In subsequent years the loss was much less. At Cornell U.S.A. it was found that 69 lb. of nitric nitrogen equivalent to 419 lb. of $NaNO_3$ were washed out of uncropped soil annually[1].

Hence it appears that either the losses of nitrate nitrogen from the soil at Nagpur are much higher than at Rothamsted, Cawnpore and Cornell or else the figures recorded for these 3 latter places are low.

A reference to Part I of this paper (p. 173) shows that in our work on the nitrate content of the soil a minimum annual loss of approximately 80 and 104 lb. of nitrate nitrogen was observed in 1925 on unmanured and manured soil respectively. For reasons there stated these figures must be on the low side.

3. *Variation in composition of well water at different depths.*

The necessity was early recognised of sampling the well water at different depths. Since August 1925 both wells were always sampled (*a*) near the bottom (*b*) half way up (*c*) just below the surface. A consideration of the analyses made at these different depths brings out points of great interest. It will perhaps be best to consider in detail only the results for the season 1926 since the sampling at 3 different depths in 1925 began late. It will be seen, however, that in general the 1925 figures where available support our general remarks on the 1926 figures.

A study of these figures shows that the 2 wells behave differently. The alkaline well shows at each sampling a uniform content of total solids at each depth on almost every occasion. As will be seen in the next paragraph, the total solid content of this well water shows only a small variation throughout the year and it would seem that the distribution of salts throughout the soil and well water has reached a condition of equilibrium so that the percolate into the well always has a more or less uniform content of total solids in solution. As regards the Students' well, it will be seen that on 13th July 1926 the first rapid rise of water level took place. Previous to that date, the total solid content of the 3 different depths sampled was approximately constant at about 60 parts per 100,000. On the 13th July, however when the rise took place the bottom layer contained 58·64 parts of total solids per 100,000 and the top layer only 50 parts. This difference in composition was maintained on each subsequent season in which the well was sampled until 3rd September 1926 after which date the well level began to fall and then the total solid content at each level became uniform. It is obvious that in the case of this well the percolate through the soil is less concentrated in total salts than the well water itself.

As regards the nitrate content at the different depths, it will be seen that in the case of the Students' well before the 13th July 1926 there was no nitrate in the well water and when the level began to rise on 13th July a considerable amount of nitrate was found in the surface layer and only minute traces at lower depths. From that date onwards until 3rd September, the surface layer of the well always con

[1]Nature and Properties of Soils, Lyon and Buckman, p. 208.

tained most nitrate, but after that date when the level began to fall and no more percolation took place into the well the nitrate was more or less uniformly distributed at each depth.

In the case of the alkaline well the nitrate content of the water at each depth is more or less uniform at each sampling though there are occasional indications that the top layer is richer than the lower depths. *e.g.*, in the analyses made in September and early October 1925.

4. *Seasonal changes in the total solid content of the wells.*

As mentioned in the previous section the two wells show a well marked difference when considered from the point of view of their total solid content at different seasons of the year. The alkaline well varies remarkably little in total solid content of its water throughout the year. In the hot dry weather when the well is at its lowest level, the water contains about 75·78 parts of total solids per 100,000. During the rains it contains rather less, *viz.*, 66·70 parts per 100,000. The Students' well, however, shows a remarkable difference in its total solid content at different seasons. During the cold weather and early hot weather its total solid content varies from 55-60 parts per 100,000. Immediately before the rains at the end of the hot weather the total solid content shows a slight tendency to increase, but when the well begins to rise it is obvious that the water percolating into it contains much less solid matter than the well water itself and by September the well water contains only 13 to 17 parts of total solids per 100,000. In the case of the Students' well it would also appear that the total solid content of the water was distinctly higher in the hot weather of 1925 than in that of 1926, whereas there was no such difference in the case of the Alkaline well. As the hot weather advances there appears to be a distinct tendency towards concentration of the water in the Students' well, but no such tendency in the case of the Alkaline well.

The cause of the difference between these two wells must be ascribed to the fact that the Alkaline well has been used for irrigation for years past and is used regularly throughout the cold weather and hot weather. There is thus continual circulation of water down through the soil and into the well, and there is a tendency for the soil water and the well water to become uniform in composition. On the other hand, the Students' well is never used for irrigation and during the hot weather there is distinct concentration by evaporation at the water surface.

It is of interest to point out here that the irrigated area surrounding the Alkaline area only measures half an acre and since there is such little change in the composition of the well water it would appear that very little lateral diffusion of the subsoil water takes place.

5. *Carbonate and bicarbonate of soda contents in the well waters.*

The two wells have been regularly analysed for carbonate and bicarbonate, but it is hardly worth while burdening this paper with the complete figures obtained. It is sufficient to say that the total solids consist mainly of sodium bicarbonate

with a small amount of normal sodium carbonate. As regards chlorides, sulphates, lime and magnesia, their quantities are small, as shown in the following analysis carried out on 9th September 1926 :—

Well	Position in well	Total solids	Parts per 100,000.			Cl.
			SO^3	CaO	MgO	
Alkaline well	Bottom	68·4	2·55	2·52	3·57	1·48
	Middle	70·8	1·81	2·60	3·49	1·58
	Top	69·5	2·63	3·12	3·58	1·62
Students' well	Bottom	48·3	1·95	2·04	1·01	1·72
	Middle	45·0	1·34	1·88	0·86	1·72
	Top	43·4	1·48	1·64	0·91	1·62

Analyses made in June 1925 gave substantially the same figures.

The question of the form in which the nitrate is washed out of the soil becomes interesting. If it were washed out as nitrate of calcium one would have expected to find large amounts of calcium in the water. As a matter of fact the water is poor in lime. It seems that the nitrate must be washed out as nitrate of soda. It is therefore suggested that when this compound denitrifies, sodium carbonate and sodium bicarbonate are formed. It is significant that the well which has been used most regularly for irrigation contains most bicarbonate and carbonate. This also is the well which suffers the largest loss of nitrate.

Hall[1] has shown that sodium carbonate is formed in the soil from sodium nitrate under certain conditions. The point is interesting on irrigated soils in a hot climate because if a well is used for irrigation the continual percolation of the well water throughout the soil and back to the well must eventually result in an accumulation of sodium carbonate in the soil. It will be of interest to recall that a few years ago when there was a shortage of water in Nagpur, certain members of the Agricultural Department utilized the water of the Alkaline well to water plants in pots and they were killed.

General bearing of the results on the maintenance of fertility in black cotton soil.

We have shown above how enormous are the losses of nitrate nitrogen from the soil at Nagpur.

On unmanured unirrigated soil this loss is approximately equal to 1,000 lb. of nitrate of soda or say 160 lb. of nitrogen. On well-irrigated highly manured soil the loss appears to be more than 3 times as great as this. However, it is unlikely that any soil in the Central Provinces receives such abnormal dressings of manure as have been applied to the land on which these figures were obtained and since moreover irrigation is not practised in the soil on which we are working we will only consider the unmanured unirrigated soil.

[1] The Book of the Rothamsted Experiments, 1919, Hall and Russell, p. 390.

Assuming, therefore, that a loss of 160 lb. of nitrate nitrogen annually takes place from unmanured unirrigated soil, it will be of interest to calculate in how many years the soil will become completely exhausted of nitrogen. It is usually assumed that nitrification takes place only in the top 9″ of soil in England, *i.e.*, the cultivated portion. In India the cultivated portion may be assumed to be not more than 6″ in depth and our figures and Charts in Part I of this paper indicate that most if not all nitrification takes place in this portion. The weight of an acre of black cotton soil 6″ deep may be taken as roughly 1,500,000 lb. This contains roughly ·05 per cent or 7,500 lb. of nitrogen. Since the annual loss from the soil of nitrate nitrogen amounts to about 160 lb. the top 6″ of soil should be entirely depleted of nitrogen in 7500/160 say 47 years. From a comparison of analyses by Dr. Leather made on the same soil 25 years ago with those made by us recently, the soil appears to have suffered no loss in total nitrogen during that period. It can only be assumed therefore that fixation of atmospheric nitrogen is taking place to a large extent in black cotton soil. It is also of interest to observe that the nitrogen content of the soil remains nearly constant from year to year and that therefore some kind of physiological nitrogen balance must be maintained in the soil. This is probably due to the fact that the conditions favouring nitrification also favour nitrogen fixation.

However, if these large losses and gains of nitrogen are taking place in the soil one would expect to find distinct variations in the total nitrogen content of the soil at different periods of the year. In order to test this many hundreds of determinations of total nitrogen have been carried out both on the unmanured and manured plots. There is no object in burdening this paper with a mass of figures but it will be sufficient to give a few figures showing the variation in total nitrogen content of the soil from time to time.

Total nitrogen content of the soil at various periods.

Date	% N. in dry soil.			
	Unmanured plot		Manured plot	
	0-6″	6-12″	0-6″	6-12″
1st July 1925	·060	·059	·071	·059
3rd August 1925	·054	·051	·058	·055
23rd September 1925	·064	·060	·058	·055
7th October 1925	·053	·052	·071	·063
25th November 1925	·067	·066	·066	·056
3rd February 1926	·051	·047	·055	·049
31st March 1926	·061	·051	·056	·048
30th April 1926	·057	·053	·066	·055
4th June 1926	·069	·052	·067	·053
30th June 1926	·075	·052	·062	·050
19th July 1926	·059	·064	·077	·069
24th August 1926	·071	·053	·065	·060
16th September 1926	·094	·049	·080	·050
21st October 1926	·066	·052	·072	·051
29th November 1926	·061	·047	·059	·048

These figures indicate that there are considerable variations in the nitrogen ɔntent of the soil from time to time.

However, there are distinct differences in the nitrogen content of the soil of ifferent parts of a plot on the same day. This is shown in the next Table.

Plot	Depth	Per cent nitrogen in the samples from different portions of the same plot — Sample number 1	2	3	4
. . . . .	0-6″	·065	·064	·059	·070
	6-12″	·055	·052	·051	·051

These differences, however, are not as great as those which occur at different eriods of the year.

In the next Table are set out figures showing the results for total nitrogen estiıation carried out in quadruplicate from the same soil sample. In one case he soil was passed through a 3 mm. sieve before weighing out the portions for nalyses and in the other case it was not sieved.

	Per cent nitrogen in quadruplicate determination on the same soil — Analysis number 1	2	3	4
oil sieved	·065	·066	·070	·068
oil unsieved	·062	·063	·061	·063

It is, we think, clear therefore that the variations in nitrogen content of the oil from different parts of the same plot on the same day and on the same plot at lifferent periods of the year are real variations inasmuch as they are much greater han the experimental error involved in the method of analysis.

PART III.

OBSERVATIONS ON THE DRAINAGE WATERS FROM TILE DRAINED AREAS.

The plots which have been described as under experiment in Part I of this paper are all underdrained at a depth of 2′ 6″ by tile drains and the outfalls are so arranged that the drainage from each plot can be collected separately.

The highly manured irrigated area surrounding the alkaline well is also similarly underdrained. As already mentioned, the Students' well has a tile drain discharging into it which drains an unmanured unirrigated area. These drains of course, do not allow of any quantitative measure of the drainage since it would be impossible to collect the drainage of the whole areas drained. The concentration of the drainage water in nitrate, however, provides some indication of the amount of nitrate present in the soil throughout the rainy season which is the only period at which any drainage normally takes place. In the case of the irrigated area surrounding the Alkaline well, a certain amount of drainage was observed during the cold weather, but this will be referred to later.

The following Table gives the dates on which drainage took place from the drains under observation, together with the nitrate content of the drainage water. The data relate to the following areas :

- (*a*) Unmanured cropped plot.
- (*b*) Manured cropped plot.
- (*c*) Manured uncropped plot.
- (*d*) Drain from unmanured area into Students' well.
- (*e*) Drain from alkaline area around Alkaline well.

(*a*), (*b*) and (*c*) are the plots (3), (4) and (2) respectively referred to on page 158 under period (*b*). In the year 1925 data for the manured uncropped plot were not available and also the data for plots (*a*) and (*b*) are incomplete as considerable trouble was experienced with broken drain pipes under those plots in that year. The drains were repaired before the season of 1926 however.

TABLE VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1925.

Date	Drain in alkaline area	Drain in Students' well	Unmanured plot cropped	Manured plot cropped	Manured plot uncropped
July 7th . .	..	0·71	..	..	..
,, 8th . .	..	..	0·74	1·16	..
,, 10th . .	2·01	..	0·26	1·93	..

Table VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1925.

Date	Drain in alkaline area	Drain in Students' well	Unmanured Plot cropped	Manured Plot cropped	Manured Plot uncropped
July 11th . .	1·55	..	..	..	..
,, 13th . .	8 a.m. 1·93 3 p.m. 1·77	0·19	..	1·61	..
,, 14th . .	1·71	0·16	..	..	..
,, 15th . .	0·90	..	..	..	..
,, 17th . .	..	0·22	..	..	..
,, 18th . .	0·11	0·19	..	1·03	..
,, 20th . .	0·10	..	..	..	..
,, 23rd . .	0·08	0·16	..	..	..
,, 29th . .	8 a.m. 0·10 5 p.m. 0·52	0·12	..	0·12	..
,, 30th . .	0·61	0·20	..	..	..
,, 31st . .	0·68	0·24	..	..	..
August 1st . .	0·60	..	..	..	..
,, 3rd . .	0·40	..	..	..	..
,, 6th . .	0·07	..	..	..	..
,, 7th . .	8 a.m. 1·04 3 p.m. 0·96	0·41	..	..	..
,, 8th . .	0·80	8 a.m. 0·34 3 p.m. 0·80	..	..	..
,, 10th . .	0·48	0·24	0·10	0·20	..
,, 11th . .	8 a.m. 0·46 4 p.m. 0·56	0·26	..	..	..
,, 13th . .	0·28	..	..	..	..
,, 14th . .	0·18	..	..	..	..

Table VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1925.

Date	Drain in alkaline area	Drain in Students' well	Unmanured Plot cropped	Manured Plot cropped	Manured Plot uncropped
August 15th . .	0·08	..	..	..	..
" 17th . .	8 a.m. 0·36 3 p.m. 0·24	..	0·30	0·21	..
" 18th . .	0·30	..	..	..	..
" 19th . .	0·28	..	..	..	..
" 20th . .	0·26	..	..	..	..
" 21st . .	0·21	..	..	..	..
" 22nd . .	0·23	..	..	..	..
" 24th . .	0·25	..	..	..	..
" 25th . .	0·24	..	0·09	..	..
" 26th . .	0·18	..	..	..	..
" 27th . .	0·25	..	..	..	..
" 31st .	0·26	..	0·05	0·14	..
September 1st .	0·24	..	..	..	..
" 2nd . .	0·20	..	..	..	..
" 3rd . .	0·20	..	0·06	..	..
" 4th . .	0·16	..	..	..	..
" 5th . .	0·15	..	..	..	..
" 7th . .	0·04	..	..	..	..
" 8th . .	0·02	..	..	..	..
" 9th . .	0·00	..	..	..	..
" 21st . .	0·29	..	..	..	..
" 22nd . .	0·16	..	..	..	..
" 23rd . .	0·09	..	..	..	..
November 10th . .	3·40	..	..	..	..

Table VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1925.

Date	Drain in alkaline area	Drain in Students' well	Unmanured plot cropped	Manured plot cropped	Manured plot uncropped
November 23rd . .	0·03	..	..	..	..
January 5th 1926 . .	1·20	..	..	..	..
No. of days on which drainage occurred . .	..	13	7	8	..

1926.

Date	Drain in alkaline area	Drain in Students' well	Unmanured plot cropped	Manured plot cropped	Manured plot uncropped
July 10th . .	3·52	..	0·86	1·7	1·54
„ 12th . .	2·44	0·56	0·80	2·00	1·36
„ 13th . .	1·76	0·44	0·86	1·60	1·12
„ 14th . .	1·84	..	0·64	1·08	0·60
August 4th . .	1·60	0·90	0·42	0·32	0·42
„ 7th . .	1·38	0·40	0·28	0·40	0·64
„ 9th . .	0·80	0·22	0·16	0·18	0·34
„ 10th . .	0·72	0·20	0·12	0·18	0·24
„ 11th . .	0·56	0·22	0·07	0·10	0·19
„ 12th . .	0·48	0·22	0·07	0·07	0·20
„ 14th . .	0·64	..	..	..	..
„ 16th . .	0·52	0·18	0·08	0·04	0·22
„ 17th . .	0·42	..	0·09	0·06	0·11
„ 18th . .	0·16	0·03	0·02	0·02	0·04
„ 19th . .	0·40	..	0·07	0·09	0·15
„ 20th . .	0·72	..	0·05	0·08	0·18
„ 21st . .	0·28	..	0·01	0·01	0·10
„ 24th . .	0·40	..	..	..	..
„ 25th . .	0·22	..	..	..	..
„ 27th . .	0·28	..	0·03	0·04	0·07

TABLE VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1926.

Date	Drain in alkaline area	Drain in Students' well	Unmanured plot cropped	Manured plot cropped	Manured plot uncropped
August 28th . .	0·26	..	0·03	0·04	0·05
,, 30th . .	0·29	..	0·01	0·05	0·09
September 1st . .	0·24	..	0·02	0·06	0·05
,, 3rd . .	0·10	..	0·00	..	..
,, 10th . .	0·18	..	..	0·01	0·01
,, 13th . .	0·03	..	..	..	..
,, 14th . .	0·06	..	..	..	..
No. of days in which drainage occurred .	27	10	21	21	21

DISCUSSION OF RESULTS.

1. Number of days on which drains were running.

It will at once be obvious that the alkaline area gave much more drainage both in the years 1925 and 1926 than any other area. The table gives the number of days on which drainage occurred. In 1925 it is not fair to consider the unmanured and manured plots under this period since as was previously noted the drains gave trouble and on being opened up late in the rains were found to be broken. However, it will be seen that in the alkaline area the drains ran on 16 days during the period July 7th to January 5th, 1926. The drain in the Students' well only ran during 13 days and ceased altogether on 11th August. The small amounts of drainage received in August and September from the unmanured plots were almost certainly not true drainage but percolations from a ditch into the broken drain near the outfall.

It is quite obvious that drainage was much more regular from the alkaline area than from the area surrounding the Students' well. Also the former area continued to give drainage right through August and September. In November this area gave more drainage as a result of the effect of 2″ or 3″ of rainfall together with irrigations which were applied. There was a further flow of drainage from this area on the 5th January 1926, against the result of the combined effect of irrigation with a fall of just over an inch of rain.

In 1926 all the drains were in good order and hence we are able to consider all the five areas under experiment. The alkaline area again gave drainage on more days than any other area, but the difference was not so marked and in this season there was no flow after September 14th in spite of irrigation in early November and a fall of 0·64″ of rain in December. The difference between the two seasons is mainly due to the fact that in November 1925 the rainfall was 3·28″, whereas no rain fell at all in November 1926. The following Table gives the rainfall for July, August and September for the years 1925 and 1926 together with the number of days on which drainage was received on two of the areas :—

Year and month	Rainfall	No. of days on which drains ran	
		Alkaline well	Students' well
1925, July	15·50	11	9
1926, July	20·86	4	2
1925, August	23·43	21	4
1926, „	17·07	18	8
1925, September	3·76	11	..
1926, „	3·63	5	..
1925 { July, August, September	42·69	43	13
1926, „	41·56	27	10

It will be seen from this Table that the rainfall in the 2 years for these 3 months was practically the same, yet the drains ran far more often in 1925 than in 1926. Taking the month of July alone, the rainfall in 1925 was 5″ less than in 1926, yet the drains ran far more frequently in July 1925 than in July 1926. It is natural to assume that besides the total quantity of rain, the amount of individual falls is an important factor in determining the quantity of drainage.

If the falls are light, the soil is able to deal with them ; but if sudden falls occur, the water either scours the surface or percolates rapidly depleting the soil of nitrate. One of the beneficial effects of drains on land such as ours is that they enable it to deal more quickly with these excess falls of rain and to prepare the soil to protect itself better from the washing or scouring effects of any subsequent heavy falls.

The more frequent action of the drains on the alkaline area must be connected in some way with the fact that the soil is irrigated throughout the dry months. In consequence, it requires less rain to raise its water content to the point at which

drainage starts than does the unirrigated soil. However, once both soils had become saturated one would have expected both to behave similarly subsequently. It may be that in the unirrigated soil there are large fissures and that much of the water which could normally pass into the drains on a moist soil pass down these fissures to the subsoil water supply. It may be, of course, that the water table in the irrigated is nearer the surface than in unirrigated soil and thus would tend to cause the drains to flow more frequently by causing a certain amount of obstruction of the downward flow of water.

2. *The nitrate content of the drainage water.*

In the first place it will be noticed that when the drains first began to flow at the beginning of the rains the drainage was richer in nitrate than on any subsequent occasion. In the case of the richly manured alkaline area and the manured plot this richness in nitrate is maintained for some time longer than in the unmanured areas.

In the season 1925, it will be seen that after the middle of July the nitrate concentrations of the drainage water fell away rapidly on the alkaline area. On the 29th July there was a distinct recovery in the nitrate concentration of the drainage water. A reference to Table I and Chart I in Part I of this paper shows that this increase corresponds to a period when the nitrate content of the soil showed a sudden increase, see also remarks on page 172. There was a further recovery in the nitrate concentration of the drainage from the alkaline area on the 7th August. On the 10th November there was a flow from the drains under this area and this flow was exceedingly concentrated in nitrate. Nitrate estimations had not been carried out in the soil of this area, but it is evident that the irrigations carried out in October and early November together with cultivation in preparation for a cold weather crop had encouraged rapid nitrification. This is also borne out by the curves for nitrate content of the well on the alkaline area at this period (Part II), which shows a rapid rise in October and November. In the season 1926 the richly manured alkaline area and the manured areas again gave drainage much more concentrated in nitrate in the beginning of the rains than any of the other areas. In general, the nitrate content of the drainage water showed a steady falling off in every case as the season advanced. This is again evidence of the fact that nitrification is most active in our soils just at the beginning of the rains. The fact that the drainage from the alkaline area was throughout steadily richer than that from any of the other areas is further evidence that the alkaline area contains much greater stores of nitrate than any of the other areas under experiment.

As will be seen, the nitrate content of drainage waters found by us reached a maximum of 3·52 parts nitrogen per 100,000 on the richly manured alkaline area. On an area manured with only 4 tons of cattle manure per acre, the maximum nitrate concentration reached was 2 parts of nitrogen per 100,000 and in the unmanured plot 0·86 parts per 100,000. It will be of interest to compare our figures with the

maximum nitrate figures obtained at Rothamsted from the drains under Broadbalk plots. These are as follows[1] :—

Plot 3 unmanured	0·7	parts nitrogen per 100,000
Plot 7 Minerals sulphate of ammonia in spring . .	2·05	,, ,, ,, ,,
Plot 9 Minerals nitrate of soda	2·03	,, ,, ,, ,,
Plot 15 Minerals sulphate of ammonia in autumn .	5·03	,, ,, ,, ,,

It will thus be seen that the figures obtained by us at Nagpur are of the same order as those obtained at Rothamsted.

Leather[2] working on the drainage from the drain gauges at Pusa and Cawnpore occasionally obtained drainage containing over 30 parts per million of nitrate nitrogen. We do not consider, however, that the conditions in the field can be compared with those in drain gauges.

SUMMARY.

1. The drainage waters are most concentrated in nitrates when they first begin to flow at the beginning of the rains. Thereafter their nitrate content shows in general a steady decrease throughout the rainy season. This confirms our work on nitrate content in soils (Part I) in which it was shown that the soil reached its maximum nitrate content early in the rains.

2. Soil which has been regularly irrigated in the dry seasons gives more regular drainage throughout the rainy season and the drains continue to run until later in the season than is the case on unirrigated soil.

GENERAL SUMMARY.

1. In the first part of the paper we have shown that when a soil is cropped with cotton or *juar* at Nagpur, nitrification is only active during the rains and mainly, in the early part of the rains. The maximum accumulation of nitrate, however takes place too early in the growth of the plant to be of much use to it. The subsequent heavy rains wash out large amounts of nitrate from the soil into the subsoil out of reach of the plant, so that at first sight nitrification is a wasteful process inasmuch as only a small amount of the nitrate produced is of use to the crop. Later in the stage of growth of the cotton or *juar* there is a shortage of nitrate in the soil as the rain has washed out the nitrate and the presence of the crop prevents efficient cultivation which might encourage nitrification. The cotton crop remains on the land till December and the *juar* crop till mid November and hence prevent early cold weather cultivation. It seems that only during the rains does nitrification normally take place in the Central Provinces soils which are under cotton or *juar* sown in the rains. If, however, the land is cropped with a cold weather crop

[1] The Book of the Rothamsted Experiments, 1919, Hall and Russell, p. 232.

[2] Records of Drainage in India, *Mem. Dep'. Agri India*, Vol. II, No. 1, p. 62.

e.g., linseed, gram or wheat, it receives efficient cultivation at the close of the rains and then such soil accumulates large amounts of nitrates in the surface 6" and a lesser quantity in the next 6". Thus in the case of land which is cropped with cold weather crops we get nitrification at 2 periods, firstly early in the rains and secondly during the cultivation of the land immediately after the close of the rains and preparatory to sowing in November. We have not so far been able to undertake a study of the effect of interculture on nitrification, but it would appear that efficient hoeing between the rows of cotton or *juar* whenever possible during the rains and at the end of the rains should prove of great benefit to the crop by increasing the nitrate supplies available to the plant. Unfortunately, weather conditions frequently make this difficult and if the land is left too late the surface dries out and then cannot be efficiently cultivated.

2. On the black cotton soil at Nagpur it appears that the soil undergoes an annual loss of nitrate equivalent to approximately 160 lb. of nitrogen. This means that the surface soil would be completely depleted of nitrogen in less than 50 years. Actually, it is shown that the nitrogen content of the soil has suffered no loss during the past 25 years. It seems obvious, therefore, that the loss of nitrogen as nitrate is counterbalanced by the fixation of free nitrogen from the air.

3. The Central Provinces cotton grower is shown to be at an economic disadvantage to his rivals in other parts of the world. In Egypt cotton is grown under irrigation in the hot weather and the conditions are ideal for nitrification. Plentiful stores of nitrate are always present in the Egyptian cotton soils, many times as great as we find at Nagpur, and there is little, if any, need in Egypt for nitrogenous fertilisers. At Nagpur during the growth of the cotton crop nitrates are only produced in any quantity early in the rains at a time when the crop is not ready to use it. In the later stages of the plant's growth the soil is deficient in nitrate. It seems inevitable therefore that a lower yield of cotton should be obtained in the Central Provinces than in Egypt. This lower yield can in part be made good by top dressings of active nitrogenous fertiliser, if applied at the right time. This right time would vary over the cotton tract, but would be as soon as there was the earliest reasonable chance of no further seriously heavy falls of rain. The question of the partial substitution of cotton by some other crop has been referred to in the paper and is also dealt with by Mr. Allan in a note at the end of this Memoir.

Certainly, a large increase in the growth of fodder crops in the Central Provinces is desirable. This would enable cattle to be better fed. They would then be more efficient for work and would produce better class cows. As long as fodder crops are neglected, very little hope can be entertained of raising the standard of agriculture in the Central Provinces.

The results indicate that efficient cultivation at the close of the rains provides sufficient nitrates for a more extended growth of cold weather crops.

NOTE BY R. G. ALLAN, M.A.,

Principal, Agricultural College, Nagpur.

My experience and a study of rainfall figures over the last 40 years will show that though we may get rain in heavy and continuous quantity after the 15th to 20th August the majority of the heavy rains, the washers out of formed nitrates, occurs before that date. After the middle of August breaks are commoner and heavy downpours of extended character, if not absent, at any rate much less frequent. If I were asked to give odds on the probable effectiveness of an application of nitrate or ammonium sulphate after the 15th of August I would be inclined to place it at about 4 to 1 in favour of an advantage from such a dressing. This, I think, is borne out by the generally paying results of 8 loads manure with the crop and 10 lb. nitrogen as nitrate put on as a top-dressing in August, when the progress of the plant has been checked by the leaching out of nitrates in July. I therefore prefer the emphasis on the importance of the utilisation of such fertilisers at the right time, presumably when the odds are against subsequent heavy rain and as I suggest sometime in the second to third week of August depending on the local rainfall average distribution.

The use of a fertiliser should come as soon as a study of local rain distribution gives this reasonable chance. In Berar, for instance, I would put this date earlier than Nagpur.

It should be noted that the work has been carried out on the wettest part of the cotton tract.

Over the larger part of the Cotton tract the rainfall ranges between 20 and 30 inches, and presumably the longer breaks would allow of the fresh formation of nitrates and the absence of so much heavy rain would lead to less washing down below the root range and to a better chance for fertilisers.

I do not dispute the statement that our conditions are not those of Egypt and we are growing cotton on less favourable terms, but I do not think that the terms through the cotton tract of the Central Provinces and Berars are universally as bad as those under study. We have not the Egyptian or irrigated area conditions, therefore we are debarred from growing cottons of their quality, but to some extent at any rate we counter that by growing a hardier and possibly a less exacting cotton, for which even if coarser, there is normally some definite market demand.

The paper shows (*a*) that generally through the cotton tract in the absence of the formation of nitrates on the scale recorded in Egypt, our cotton is grown on less favourable terms, and that yields can only be brought up by the judicious use of fertilisers (which makes our cost higher) and (*b*) that specially in the wetter tracts to the East and on possibly the lower lying fields elsewhere, where the natural re-

ceipt is augmented by the flow from higher areas, cotton is being grown under such obviously defective nitrate conditions as to be unlikely to pay, except under boom conditions. I would note that the cultivator realises this. About half the area under cotton in the Nagpur District is purely the result of a boom and will go back to *rabi* or *juari* with the end of the boom as it has done so more than once in past history.

There are, however, wide areas on which cotton can be economically grown, with normally assured profit, possibly on $3\frac{1}{2}$ million acres out of the 5 million to which the crop has been pushed by recent prices.

Groundnut is the most hopeful substitute as a commercial crop to replace cotton. It will, however, do best in the conditions where cotton is likely to be remunerative, *i.e.*, on well drained areas, where the rainfall is not too heavy, though on the experience of the past year it can, provided drainage is fair, stand more rain than cotton.

In the wetter tracts, either climatic or soil, an extension of *rabi* is possible, but over large areas of the cotton tract, the nature of the rains of the past 20 years makes the growth of *rabi* crops less safe than *kharif*.

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Memoirs of the Department of Agriculture in India

Soils of the Punjab

BY

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Agricultural Chemist to Government, Punjab

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

Calcutta: Government of India
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PREFACE

During the past twenty years that the Chemical section of the Agricultural Research Institute, Punjab, has been functioning, a considerable number of investigations and analyses have been carried out on the Punjab soils. While these, with the exception of analyses undertaken during the past two years, have not fallen into any systematic scheme of investigation on the Punjab soils as a whole, and no comprehensive survey of these soils has been undertaken, it is proposed to present in the following paper the collected data which have accumulated from the investigations so far carried out, in the hope that they may give a skeleton outline of the more important soil features of the various districts of the Punjab and indicate some of their distinguishing characteristics.

AGRICULTURAL COLLEGE, LYALLPUR.

17th May, 1928.

P. E. LANDER, M.A., D.Sc., A.I.C.,
RAMJI NARAIN, D.Sc.,
and
MEHTA MOKAND LAL, B.Sc., L.Ag.

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1. Main Features of the Province.

Before attempting to describe the soils of the Province or give details of their chemical and physical composition, it is desirable to describe the main general features of the Province as these exercise no small influence in interpreting the figures of analysis and consequently the treatment which a soil may require.

(*a*) Physical and Geological Factors.

The Province falls into five main physical divisions :— (*a*) The Himalayan Region, (*b*) The Himalayan Sub-montane, (*c*) The Arid Plateaux of the Salt Range, (*d*) The Arid South-Western plains and (*e*) The western portions of the Indo-Gangetic plain.

Of these the first three are small in area and the first and third are not of great importance from an agricultural point of view ; the Sub-montane, however, is the most fertile and wealthiest in the Punjab. The remaining two divisions are of vast extent and fertile towards the South, where they encroach on the plains of Sind and Rajputana, and depend almost entirely on canal irrigation for their prosperity.

Geologically, the Punjab falls into three natural divisions :—The plains, the Salt Range and the Himalayas. The plains, which consist almost entirely of the Indo-Gangetic alluvium, form the chief subject of study in this paper. In the north of

the Province the Salt Range stretches from the Jhelum valley on the east to the Indus on the west, and crops up again beyond that river. The Himalayas form the eastern boundary of the Province, extending from the south-east to the extreme north.

(b) METEOROLOGICAL FACTORS.

The Punjab being an inland Province, the climate over the greater part of it is of a most pronounced continental character, extreme summer heat alternating with great winter cold, but its diversified surface, including montane, sub-montane, and plain zones, very largely modifies the temperature, weather and climate in different parts of the Province. The Punjab may accordingly be divided into four natural divisions, in each of which the general meteorological conditions are believed to be fairly homogeneous (Diagram 1).
These are :—

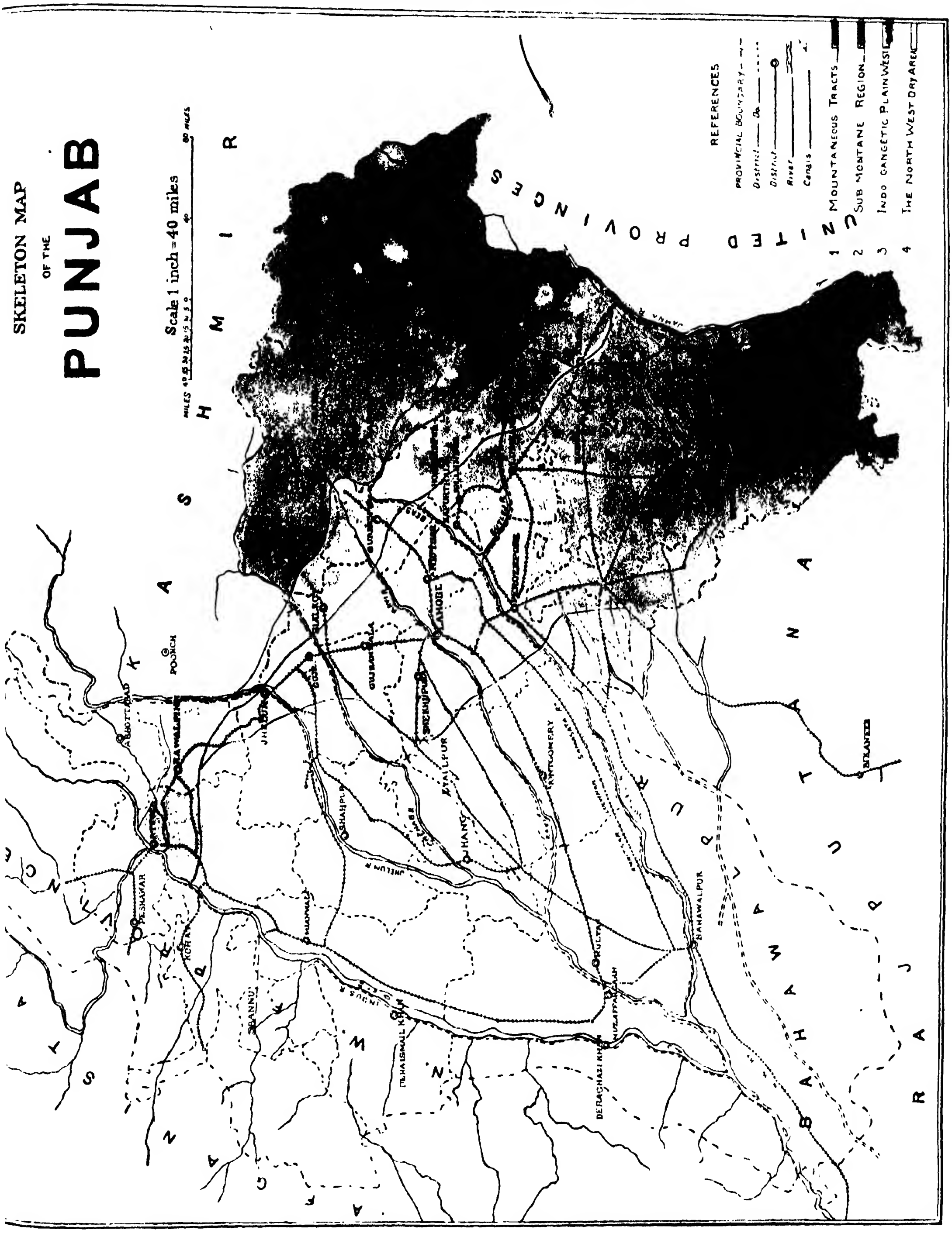
1. The Himalayan (*e.g.*, Simla and Murree).
2. The Sub-Himalayan (*e.g.*, Ambala, Ludhiana, Gurdaspur, Sialkot and Rawalpindi).
3. The Indo-Gangetic plain west (stations extending as far as Lahore).
4. The North-West dry area (stations Mianwali, Sindh Sagar, Muzafargarh, Dera Ghazi Khan and Multan, etc.).

Taken as a whole, the Punjab has in normal years two well defined rainy seasons. The first, or period of the north-east monsoon, extends from the end of December to the end of February or even upto the middle of March. During this period the Punjab experiences what are generally known as winter rains. The second period of rainfall, the result of the north-west monsoon, lasts from the end of June to the middle of September. The rainfall is naturally heaviest in the Himalayan and sub-montane regions, the highest average received being 126″ at Dharamsala, while the average for the region is nowhere less than 36″. In the plains the rainfall decreases rapidly as we pass from the hills. The sub-montane zone, which skirts the foot of the hills, and of which Rawalpindi, Gurdaspur and Sialkot may be taken as typical stations, has an average annual rainfall of 30″ to 40.″ The Eastern plains from Delhi to Lahore, belong to the West Indo-Gangetic plain, and have a mean rainfall of about 24″. To the west and south-west lies the dry area characterised by an extremely light and variable rainfall, and heat and dryness in the hot season, extreme even for the Punjab. The ordinary south-west monsoon winds from the Sindh and Kathiwar coasts encircle, but do not actually blow into this area, which therefore gets very little rain from this source, though it occasionally receives heavy cyclonic downpours from storms which have travelled westwards from the head of the Bay. Montgomery and Multan are typical stations of this tract.

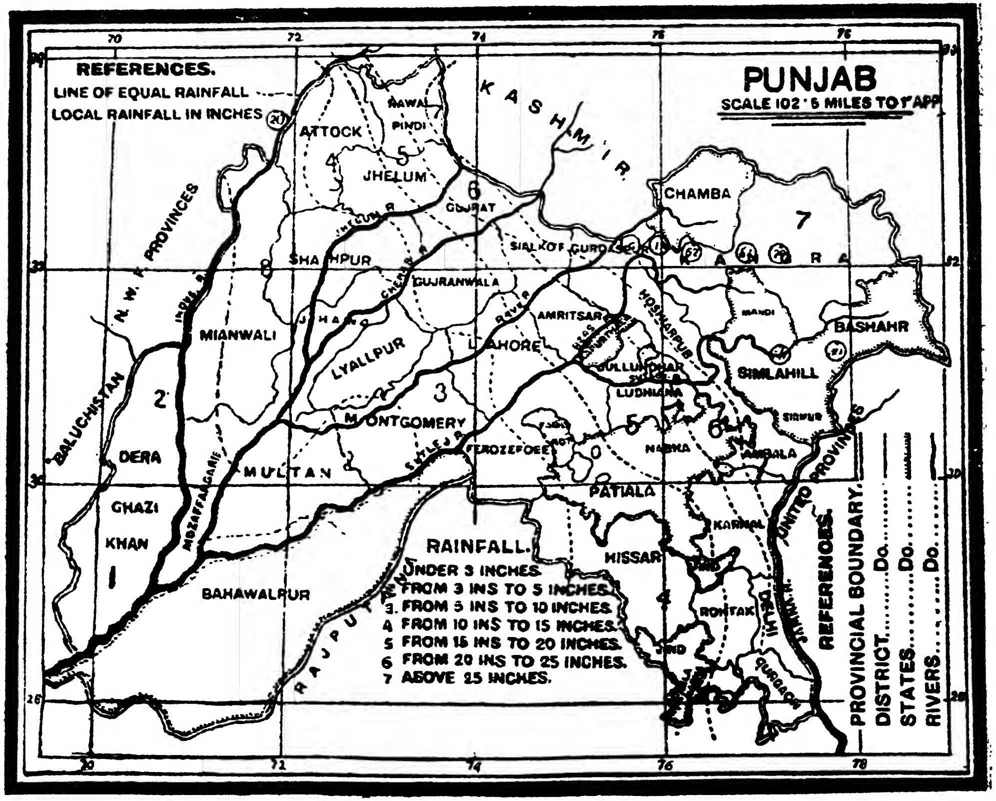
The amount of rainfall for different regions of the Punjab is represented in Maps A and B. The plains, owing to their arid nature and remoteness from the sea, are

DIAGRAM I.

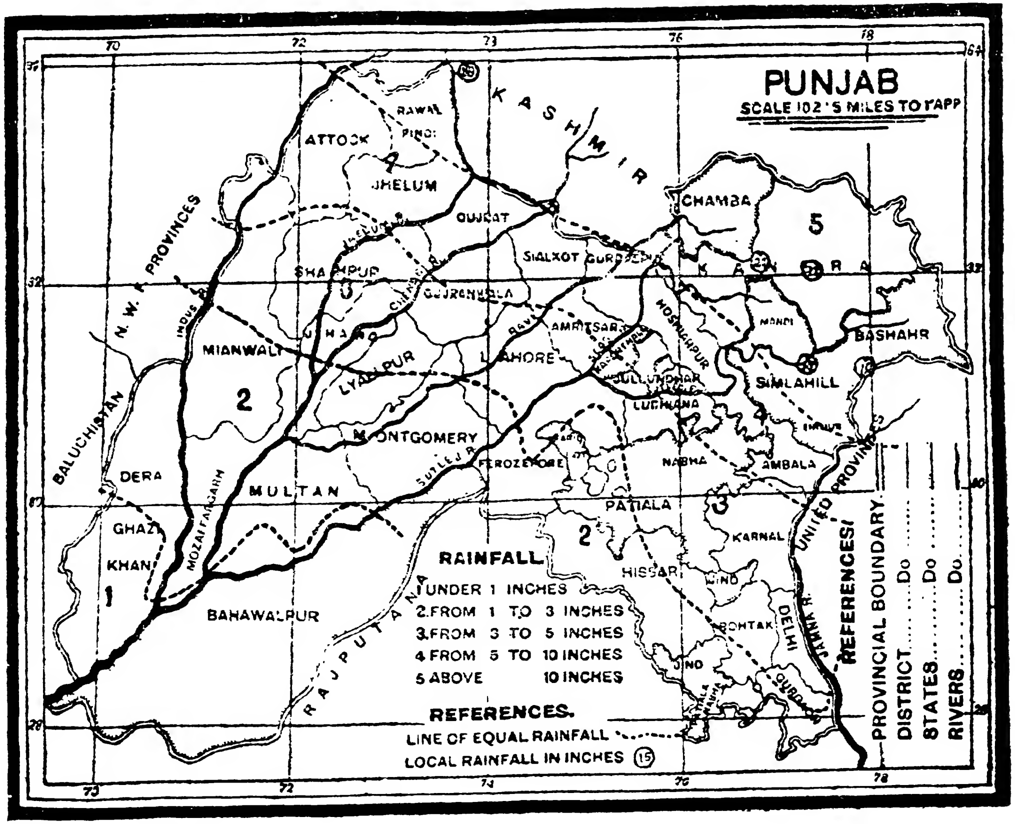
Showing, different Physical Divisions of the Punjab.



MAP A SHOWING AVERAGE RAINFALL IN INCHES IN THE PUNJAB IN THE MONTHS JUNE TO SEPTEMBER.



MAP B SHOWING AVERAGE RAINFALL IN INCHES IN THE PUNJAB IN THE MONTHS OCTOBER TO MAY



subject to extreme variations of climate. In winter the degree of cold is as intense as may be found anywhere in the plains of India. In the latter part of December and January and sometimes in February the night temperature commonly falls below freezing point, while by day the thermometer does not as a rule rise above 75°, and for four months of the year the Punjab climate with its bright sun and keen invigorating air cannot be surpassed. In summer, on the other hand, the fierce dry heat is exceeded only in Sindh. In June the thermometer commonly reaches 115°-121°, while the night temperature averages from 75°-90°.

(c) Artificial Irrigation.

The Punjab possesses the greatest irrigation system in the world. In the year 1926-27, out of a total cropped area of 30,406,911 acres, 13,911,456 acres were irrigated and of this area, 72 per cent. (10,018,746 acres) was served by canals, 408,580 acres by tanks and other sources of water supply, and 3,484,130 acres from wells (chiefly in the districts of Jullundur, Sialkot, Hoshiarpur, Gurgaon and Ludhiana). The canals of the Punjab are not lined, and owing to the velocity of the water carry fairly coarse silt. They are designed at a slope which causes slight silting in the *Kharif* when the rivers are in flood, and they scour to some extent in winter.

(d) Underground Water.

Particulars regarding the level of the sub soil water are given in the body of the paper with the description of the particular soils. Lately, on account of the construction of the big canal systems and consequent seepage, partly due to an interruption in the natural drainage at certain places, water has accumulated in the upper soil layers to such an extent as to cause water-logging. Consequently, such soils are going out of cultivation. Another effect of canal irrigation has been the rise of the subsoil water table at many places. For instance, in Lyallpur the water table is rising at the rate of one foot every four years. In the Lower Chenab, figures for a number of years show that the rise of the water level at certain places is 1½ feet per annum.[1] In some parts the water table has already reached the surface and caused water-logging. The percentage of water-logged area on the Punjab canals is so far small - not more than 1 or 2 per cent.; but the serious aspect of the question lies in the fact that the rise of the water table is general throughout the Doabs, and there is no evidence so far of any slackening or reduction in this rate. There is no question whatever that when the water table gets within 10 feet of the surface in any tract, the future prosperity and productivity of that part is in a critical position. From this depth the rise of the water by surface tension and its evaporation from the surface becomes considerable. This goes on constantly, and ' Kallar ' or Salts thus tend to accumulate in the upper soil layers.

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[1] Roberts, W; & Faulkner, O. T. A Text-Book of Punjab Agriculture, *Civil and Military Gazette Press*, Lahore, 1921.

On the other hand, in some districts such as Jullundur, the water level, owing to heavy demands on the wells, has been gradually falling during recent years.

(e) Agricultural Features and General Soil Conditions.

Excluding the Himalayas and other hill tracts and the Ravines of Rawalpindi, Attock, and Jhelum districts, the vast alluvial plain of the Punjab is broken only by the wide valleys of its rivers. Its soil, for the most part, is a sandy loam, interspersed with patches of clay (samples 199 and 226, Table I) and tracts of pure sand (samples 115 and 223, Table I). The soils of the Himalayas and lower ranges resemble those of the plains, but both sand and clay are rarer and the stony area is considerable.

The Punjab has two harvests : The *rabi* (*Hari*) or spring, sown mostly in October-November and reaped in April-May ; and the *kharif* (*Sawani*) or autumn harvest sown in June --August, and reaped from early September to the end of December. Both sugarcane and cotton though sown earlier are autumn crops. With the development of irrigation the tendency has been for intensive cultivation in the *rabi* to replace the extensive cultivation of the *kharif*.

The principal spring or *rabi* crops are wheat, gram and barley. Wheat occupies a much larger area in the Punjab than any other crop, *viz.* 30 to 35 per cent. of the total cropped area. The actual area for the year 1926-27 was 9,379,462 acres. After wheat, gram is most extensively grown, covering about $4\frac{1}{2}$ million acres, of which only 12 per cent. is irrigated. The largest areas are found in Ferozepur, Hissar and Rohtak. Should winter rains be favourable, wheat or barley gives a good yield ; whereas gram subsists best when the rainfall is less. The area under barley in the Punjab is rather over a million acres, *i.e.*, about 1-10th of the area under wheat, and the crop is chiefly grown in the districts of Hissar, Ferozepur and Gurgaon, mostly on light unirrigated land.

Of the autumn or *kharif* crops, rice, cotton and sugarcane are the most important. Rice is grown chiefly in the Kangra, Gurdaspur, Amritsar and Gujranwala districts. The plant grows best in a very heavy soil where plenty of water is available ; stagnant water is, however, unfavourable for its success.

The area under cotton has been liable to considerable variations in the last few years owing to the great fluctuations in price. In 1924-25, a record area of 2,326,335 acres was under cultivation. Excluding the montane and sub-montane areas, cotton is grown wherever irrigation is possible and the land not excessively sandy, cotton being almost exclusively an irrigated crop, in the Punjab.

The Punjab, amongst all the Indian Provinces, has the second largest area under sugarcane, usually varying between $3\frac{1}{2}$ and $4\frac{1}{2}$ lakhs of acres.* The best areas for the growth of the crop are in the south-east of the Province, in the districts of Rohtak and Karnal, the next best being the eastern districts such as Gurdaspur and Sialkot. The rainfall in the Punjab is nowhere sufficient for the growth of

* Lakh=100,000.

sugarcane, and thus this crop can only be grown either under irrigation or where, as near the beds of rivers, the underground water is sufficient. Cane can be grown profitably on land which is moderately heavy, but it is useless to try to grow it on very light soils.

Such, in brief, is the description of the chief physical features of the Province and we may now consider the main theme of our paper, *viz.*, the chemical and agricultural characteristics of different types of soil met with in different regions of the Province. These have been arranged according to the four general meteorological divisions given above.

2. The Himalayan Tract.

The Himalayan tract includes more than half the state of Jammu and Kashmir in the extreme north-west while the district of Kangra and the Simla hill states form the south-east part of the Punjab Himalayas; east of this lies the Kumaun division of the United Provinces, followed by Nepal, Sikkim, Bhutan, etc. In the Punjab we are concerned only with the Kangra and the Simla hills.

The Agricultural parts of the Himalayas with few exceptions are of secondary importance, to the plains the chief food grains cultivated in the outer ranges being rice, wheat, barley and maize. In the hot moist valleys, chillies, turmeric and ginger are grown. At higher levels potatoes have become an important crop, and in Kulu and Kumaun, fruits, such as apples, pears, cherries, plums and strawberries have been successfully naturalised. Two crops are obtained in the lower hills, but cultivation is attended by enormous difficulties, owing to the necessity of terracing and clearing land of stones, while irrigation is only practicable by the aid of long channels winding along the hill sides from the nearest suitable stream or spring. As the snowy ranges are approached, wheat and buck wheat, grown during the summer months are the principal crops and only one harvest in the year can be obtained. Tea gardens were successfully established in Kumaun during the first half of the 19th century, but the most important of these are situated in Kangra.

1. Kangra.

With the exception of the examination of some samples from the district of Kangra, very little work has been done in connection with the montane tract of the Province. As mentioned above, the Kangra district is eminently suited for growing tea and fruits. Rice is also grown at many places in the district although it is not of superior quality, and the soils examined from this district have been confined to tea gardens only. Most of the tea gardens are situated in the valley at a height varying from 2,500 to 4,500, or even 5,000 feet in some cases. For at least six months in the year the climate is warm and moist and the rainfall is not less than 100 inches per annum, but even at these elevations the cold is never so severe as to injure the growth of the tea plant. Hot winds are unknown in the Kangra valley.

The analyses of some representative soils of the tea estates in this valley are given in Table I Nos. 1-7. It will be seen from an examination of these soil types that tea is being grown on a variety of soils. For example No. 1 is a light sandy loam ; Nos. 2, 6, and 7, medium to heavy loam ; while 3, 4 and 5 may be designated stiff clay soils. From a study of their chemical composition, however, it will be seen that with the exception of Nos. 1 and 4, the others are comparatively rich in nitrogen. The soils also appear to be rather deficient in lime, but are sufficiently alkaline to allow the conservation of a large proportion of combined nitrogen. Soils No. 2, 5, 6 and 7 are exceptionally rich in nitrogen and potash for tea soils. On the other hand, with the exception of soils Nos. 2 and 4, they are all below par in phosphoric acid and in this respect compare only with second grade Assam soils. Phosphoric acid is a manurial constituent of great importance in tea soils, since it not only serves to stimulate ripening but it also induces early development of the young plant and secures a sound establishment of the root system. A light dressing of crushed bone meal every now and then is likely to improve these soils considerably. The question of the magnesia content will be discussed separately later.

3. The Sub-Montane Tract.

The Sub-montane tract includes the districts of Ambala, Hoshiarpur, Gurdaspur, Sialkot, Rawalpindi and Attock. From the southern foot hills of the sub-Himalayas there extends a width of high level territory flanked by an outer ridge of recent formation known as Siwaliks--a line of broken and disintegrating hills which mark the first step upwards from the plains. The sub-montane tracts of the Punjab are enclosed between the Siwaliks and the Himalaya, and the upland valleys skirting these mountains include some of the most fertile and beautiful of the Indian low-land formation in the north-west.

The districts of Rawalpindi and Attock, situated on an undulating plateaux, comprise wide rolling plains broken by wild, irregular, and in the districts of Attock, mostly barren ravines and hills of very varying magnitude. There is no regular irrigation, and agriculture in these districts depends almost entirely on rain water which, except in some parts of Attock, is plentiful. The chief crops grown are wheat and barley, with *jowar* (*sorghum vulgare*), *bajra* (*Pennisetum typhoideum*), gram, and pulses in addition in the Rawalpindi district, and millet and maize in the Attock district.

The remaining districts present many points of similarity in their physical and agricultural condition. As already stated, they constitute one of the most fertile and richest tracts of the Punjab. The chief sources of irrigation are wells, natural streams and canals. These, coupled with an abundant rainfall, secure for the crops a plentiful supply of water. The chief crops are wheat, barley, maize and sugarcane. Cotton is grown in the Hoshiarpur districts to some extent; but there is neither any cotton nor sugarcane worth mentioning in the Ambala district.

1. *Ambala.*

The main portion of this district is a plain which descends from the Siwalik hills towards the south-west. This plain is fertile, and mainly composed of alluvial loam, intercepted at intervals of a few miles by gulleys through which the hill torrents descend. It is also interespersed with blocks of stiff clay soil, which in years of scanty rainfall are unproductive, thus rendering the tracts where they occur liable to attacks of famine.

Sample No. 8 in Table I represents a sandy loam tract of the *barani* area of the same district. This soil is seldom manured and generally gives a yield of from 7 to 8 maunds of wheat ; 10 to 12 maunds of maize, or 3 to 4 maunds of cotton. The usual rotation practised is wheat-wheat, or wheat-maize, cotton. Sample No. 9 represents a soil on which only rice is grown, and whose sub-soil water is generally about 14 ft. below the surface.

Soils No. 10—14, are taken from the Military Dairy farm at Ambala Cantonment which encloses an area of about five hundred acres. No. 10, a heavy loam, is a representative of one of the best soils of the district and gives a very good crop of wheat averaging about 16 maunds per acre. No. 11 is a sample of sandy soil suitable for growing cotton and wheat ; No. 12 is a soil from a pasture land which grows under *barani* conditions very good crops of grasses, Anjan and Baru. No. 13 is a sample of sandy soil which yields good crops when manured, while No. 14 is suitable for the cultivation of barley and gram.

2. *Hoshiarpur.*

The district is divided into four Tahsils, *i.e.*, Hoshiarpur, Garhshankar, Dasuya and Una.

A peculiar feature of the district are the Chos or hill torrents, which rise in the hills below the watershed, leave them by a narrow outlet and widen on their way to the plains until they break up into a number of branches, thus spreading like a net work over the plains. At an earlier period the silt washed down from the Siwaliks must have formed an alluvial plain to their west and caused its fertility, but owing to the deforestation of those hills, the Chos have for a considerable time been destroying it. Dry in the rainless months, they become raging torrents after heavy rains, and, passing through the sandy belt which lies below the western slopes of the hills, they enter the plain, at first in fairly well defined channels, but finally spread over its surface and bury the cultivation under infertile sand.

The Siwalik hills, which form the back bone of the district, are composed for the most part of soft sand stone from which a belt of light sandy loam known as the *Kandi* tract, lying immediately at their foot, is formed. This soil requires frequent, but not too heavy, showers, and the tract is to a large extent overspread with shifting sand blown from the torrent beds. Lying parallel to this is a narrow belt, in which the loam is less mixed with sand, and this is in turn

followed by the exceptionally fertile *Sirwal* belt in which the water level is near the surface and the loam little mixed with sand except where affected by the hill torrents, and is of a texture which enables it to draw and retain the maximum of moisture. Garhshankar is a tract of clayey land, while north of Dasuya and beyond the range of Siwaliks denudation, is an area probably formed by the alluvium of the river *Beas* and one of the most fertile in the district. The soil of the Una valley is for the most part a good alluvial loam, specially fertile on the banks of the Sutlej.

Two samples of soil have been examined from the latter tract; the first, No. 15 in Table I was taken from the village Premgarh and appears to be very suitable for wheat. The second No. 16 was taken from the village Kamalpur and represents land generally put under sugarcane, the yields being about 20 maunds of wheat; and 40—50 maunds of *gur* per acre from the Katha variety of cane, known as Chan in the district.

Both these soils are irrigated from wells in which the water level is 28 ft. deep. The land is fairly well drained and the most common rotation practised is wheat, maize, *senji* (*Melilotus parviflora*), sugarcane (maize is manured in the rotation).

3. *Gurdaspur.*

Of the four Tehsils which comprise this district, the southern two, Batala and Gurdaspur, are situated between the Bias and the Ravi rivers and present the ordinary features common to the sub-montane tracts of the Province. The tehsil of Pathankot towards the north of Gurdaspur is the most varied part of the district, containing as it does the low foot hills, outlying spurs of the foot hills, the valley, and the plains. The Tehsil of Shakargarh includes land which is somewhat different from the rest of the district, most of the land in this tehsil being very fertile, highly cultivated, with a somewhat higher sub-soil water level.

A marked feature of the Bari Doab is the existance of numerous *Chambs* or Swamps, the most noted of which is the *Khanuan Chambh.* We had occasion to examine the soil from Keshopur Chambh near Gurdaspur, the analysis of which is given later.

Nos. 17—21 and 48—53 of Table I represent samples taken from the Gurdaspur and Pathankot tehsils, whereas samples 22—27 were taken from a field on the Government Agricultural Farm, which was under manurial experiments for sugarcane, and 28—33 are representative samples of soils which have proved to be more suitable for growing sugarcane in the Gurdaspur and Batala tehsils.

Of the first five samples, No. 17 was taken from a typical rice field of the Pathankot tehsil; No. 18 from a typical rice field of the Gurdaspur tehsil, No. 19 from the sugarcane growing tract; No. 20 from a field which grows very good wheat and No. 21 represents a soil which appears to be suitable only for inferior crops such as *mash* (*Phaseolus radiatus*) and *moth* (*Phaseolus aconitifolius*).

Nos. 34–46 show analyses of some other soils from the district, while No. 47 is from a plot under green manuring experiments at the Government Agricultural Farm. Samples No. 48 and 49 are soil and sub-soil samples from fields A-1(*a*) on the farm. This soil, a rich loam, has been yielding good crops without any manure, the rotation followed being maize, *senji*, sugarcane. No. 50 and 51 are specimens of soil from Keshopur Chambh, a low lying piece of land about 2 to 3 thousand acres in extent, which grows luxuriant crops of grass such as *dubh*,[1] *chimbar*,[2] *palwanh*,[3] *siru*,[4] *pannih*,[5] *kahi*,[6] *nari*,[7] and *khabbal*,[8] etc., which, however, are available only for a period of about 3 months from August to October. The surface soil of the Chambh is a sandy loam, but on descending to the second foot, one meets with a stiffer soil, which probably accounts for the impervious nature of the land. Very good crop of rice were reported to have been raised from this tract some years ago. The land, however, has deteriorated in recent years, partly owing to the appearance of 'Kallar,' a condition due in some measure perhaps to the natural drainage in the middle of the tract having ceased to function.

Nos. 52 and 53 are samples of soils from the village of Jandoal on the Pathankot-Dalhousie road near Chakki. This soil, a medium loam, normally grows maize but is not suitable for other crops.

4. *Rawalpindi.*

This district may be divided into three main portions based on its more prominent features :—

1. The montanous portion consisting of the Murree Tehsil and the northern portion of the Kahuta Tehsil.
2. The hilly and sub-montane tract, including the spurs of the Margalla range, the area lying at the foot of the Murree hills, and the steep hills on the western bank of the Jhelum and the Rawalpindi Tehsil.
3. The plains, or Pothwar portion, including the whole of the Gujar Khan, the south-east portions of the Rawalpindi Tehsil, and the south-west portions of the Kahuta Tehsils.

Samples No. 54–59 were taken from the Military Dairy Farm at Rawalpindi which may be considered representative of the most fertile spots in the whole district. The farm consists of an undulatory piece of land with fields worked out in terraces, the soil of which consists chiefly of a reddish stiff clay. Samples No. 54 and 55 are from block 2 on the farm and represent a medium silt soil ; the rota-

[1] *Eragrostis Cynosuroides.*
[2] *Eleusine Flagellifera.*
[3] *Andropogon Pertusus.*
[4] *Imperata Arundinacea.*
[5] *Andropogon Muricatus.*
[6] *Saccharum Spontaneum.*
[7] *Paspalum Distichum.*
[8] *Cynodon Dactylon*

tion followed is *jowar*, barley, wheat-*jowar*-fallow. Samples No. 56 and 57 (block 3) represent a clayey loam, well suited for growing crops such as, *jowar*, wheat and barley. Samples No. 58 and 59 (block 2 sandy portion) are typical of the sandy soils, the rotation followed being *jowar-jowar*.

5. *Attock*.

The Attock district comprises the western portions of the rough plain country lying between the Indus and the Jhelum rivers, and under the mountains of Hazara. The district is divided into four Tehsils, *i.e.*, Attock, Talagang, Pindi Gheb, Fateh Jang, administrative divisions which correspond fairly closely with the natural divisions. The Attock Tehsil, though not itself homogeneous in nature, differs somewhat from the rest of the district, and may be divided into three main portions, *viz.*, the *Chhachh* plain, the most fertile and richest portion of the district; the *Sarwala* tract a desert of waterless sand, and the *Nala* tract, a level plain dotted here and there with barren hills and crossed by ravines. The Talagang Tehsil consists of a high lying plateau, scoured by the deep beds of numerous torrents and fettered everywhere by innumerable small gullies and ravines. The Fateh Jang tehsil comprises the country lying between, and on both sides of the *Sil* and *Swan* streams. North of the Sil the high lands ascend in a wilderness of irregular ravines scoured by torrents. The valley of the Swan consists of the broad and sandy bed of the streams flanked by wide stretches of rich alluvial loams, while beyond the Swan is the less fertile land known as *Wadala*, which, on its southern side, comprises the country known as Asgham, a narrow undulating plain of small villages with light fertile soil and good *barani* cultivation. The south-west corner of the Pindi Gheb Tehsil is a wild and mountainous country where cultivation is carried on either in the sandy soil found on the top of the stony plateau or in deep valleys, banked up at their lower ends in order to arrest the soil washed down by the floods. The remaining portion of the central plateau known as the *Jandal*, is a tract, the characteristic features of which are undulating stretches of fine sandy soil pre-eminently suitable for gram crops. The rest of the Tehsil consists of high open country, mostly barren and unproductive, but containing here and there more fertile depressions. Towards the east at Fatehjang, the country is a bleak, dry, undulating, often stony tract, broken by ravines and pitted by outcrops of rock.

Thus the district consists of high mountain tops, bleak and unfertile, in the main, but with very fertile spots at intervals, low lying valleys, and vast level plains: in fact all the various types of physical configuration possible are met with, and any wide uniformity of soil type in such a tract is not to be expected. The soil types met with are residual and cumulose, culluvial and alluvial and even loess, in fact almost all possible soil types are to be seen. In places, the hard rocks may be seen in the process of disintegration and present a very instructive study in methods of soil formation.

In Table I are included analyses of 31 samples of soil, taken from different villages in the Fatehjang Tehsil, with the exception of Khunda which is in the Pindi Gheb Tehsil. The country covered by most of these soils is a part of the Nala tract, a level plain, dotted with barren hills and streaked with ravines and streams. Analysis confirms our expectation that the soils from such a tract do not fit in in any orderly scheme of soil types. The figures are given as indicative of the different types of soil met with in the locality south of the Kala Chitta range. The soils examined were mostly taken from the Fatehjang Tehsil and only three samples representing the first three feet were taken from the village Khunda in Pindi Gheb Tehsil, and one sample of black surface soil from the same village. The soils from the different villages were all taken from a three foot column, each foot being kept separate. The soils from Ajjuwala (Nos. 63—65) are the heaviest of all the samples examined. As one travels from the village towards the south-west, the soil gradually changes from a light medium soil at Kharala Khurd (Nos. 66—68) to a sandy soil at Khunda (87—90), and a similar variation in the mechanical composition is noticeable as we move towards the north-east to Jhang (69—74) and Neka (75—80). The soils from Fatehjang-Sadkal (Nos. 60—62) and Doian (84—86) are all light medium soils. All the soils in the Fatehjang Tehsil and also those in the Pindi Gheb Tehsil a little further to the left hand side of the Rawalpindi-Kohat Railway line are light medium soils, while those on the right hand become gradually heavier as we travel from Rawalpindi to Gagan, a distance of about 30 miles. These remarks are, however, based upon the assumption—which as the physical description of the district given above shows may not always be correct—that the soils from any one village are typical of a considerable area surrounding that village.

The popular belief as to the clayey nature of these Ajjuwala soils is confirmed by mechanical analysis; but the soil samples examined from Khunda which are popularly regarded as similar in type to the Ajjuwala soils are sandy and not clayey. In fact, out of all the samples examined these are the only soils which are typically sandy. The soil from Fatehjang-Sadkal are shown by mechanical analysis to be heavy medium soils from which Kankar is absent and not sandy as commonly believed. All the other soils from the villages Kharala-Khurd, Jhang, Neka, and Qutbal (81—83), known as lime stone or *kankar* soils, are medium or light medium soils.

The Lime and Lime-Magnesia ratio.

The figures for these (average for a three feet column) are given below.

The popularly known *kankar* and lime stone soils from the villages Kharala Khurd, Neka, Qutbal and Doian, have all a high lime content varying from 8 per cent. to 13 per cent., and all of them, with the exception of the soils from Kharala Khurd, have an equally high lime-magnesia ratio. Of all the soils examined, those from Kharala Khurd show the highest figures for magnesium as far as the third

foot. Consequently, their lime-magnesia ratio is much less than that of the other soils referred to above.

Village	Lime	Lime : Magnesia	Physical classification
	per cent.		
Sadkal	1·97	1·70	Heavy medium.
Ajjuwala	12·86	7·97	Clay.
Kharala Khurd	7·86	3·41	Light medium.
Jhang (irrigated)	5·73	2·87	Medium.
Jhang (*Barani*)	4·45	2·98	Do.
Noka (irrigated)	8·91	7·33	Light medium.
Noka (*Barani*)	10·01	8·61	Ditto.
Qutbal	11·84	7·15	Ditto.
Doian	13·21	8·37	Ditto.
Khunda	5·77	3·38	Sandy.
Khunda (black soil)	3·44	1·64	Ditto.

It is remarkable that the "Limestone soils" from Jhang do not contain as much lime as the lime and *kankar* soils from other places. A still more remarkable fact is the very high percentage of lime found in the clayey soils of Ajjuwala. This should have modified favourably and to a very large extent, the hard, impermeable character of the soil making it as good a producer of crops as any normal soil, yet the crops grown at the time when the samples were taken presented a very poor appearance. But, as mentioned in the physical description of the district, much depends upon the character of the rocky substratum.

Iron.

The quantity of iron present in these soils is not very high and does not vary very much, with the exception of the Neka soils which contain somewhat less iron. This excludes any explanation as to the red colour of the soil being due to the high proportion of iron present. The white soils from Kharala Khurd contain more iron than the black soils from Khunda.

All the soils are rich in potash and are certainly not deficient in phosphates, when we take into consideration the fact that most of the Punjab soils have a P_2O_5 content lying between 0·1 and 0·2 per cent.

Nitrogen.

The amount of nitrogen present in these soils compares favourably with that found in most of the Punjab soils, the average 0·066 per cent. being slightly higher than the average for the latter. Even the second and the third foot columns contain 0·055 per cent. nitrogen.

The figures for "Loss on ignition" which are usually taken to represent roughly the amount of organic matter present in any soil, are high when compared with other Punjab soils.

These soils, as revealed by chemical analysis, are not deficient in any of the essential plant food ingredients, yet they are not so fertile as other Punjab soils. Perhaps this is due to the fact that these soils lack the necessary plant food material in the available form.

The figures for the amount of total solids (Table II) present in the water extract of these soils are much higher than we ordinarily meet with in the alluvial soils of the Punjab. This coupled with the fact that all these soils contain on an average 0·2 per cent. of sodium bicarbonate may explain to a certain extent their lesser fertility as compared with rich soils in other parts of the Punjab.

4. The Indo-Gangetic plain.

The Peninsula of India is separated from the northern area of upheaval, of which the Himalayas are the southern revetment, by a broad interval of low flat country known as the Indo-Gangetic depression, which extends from the delta of the Ganges to the delta of the Indus. Since the geological era in which occurred the parting of waters, when the Indus first started westwards and the Ganges turned its currents to the east, the physical character of the two basins has rapidly diverged.

In the Punjab the Indo-Gangetic plain extends westwards as far as Lahore. The whole of the Gangetic basin is within the influence of the south-west monsoon rains, and those portions of the Punjab plain which represent an extension of the Gangetic basin are benefited by these rains. The western tracts, however, which form the basin of the Indus and its affluents, present physicl characteristics differing in many essentials from those of the Gangetic basin proper. From the districts where the plains spread southwards, the Punjab presents the picture of a flat treeless landscape except in the areas served by the canals. There was a time when forests grew in the Sind valley, but they have long ago disappeared and it is probable that with this disappearance the meteorological conditions of the Indus valley have greatly changed.

No part of the Indus valley is subject to a regular and systematic rainfall in the monsoon season, although the fall gradually increases from Sind towards Lahore. Thus the climate of the valley is hot and dry. Irrigation has, however, greatly developed lately and there are green areas around the Indus river and the newly

spread net work of the Punjab canals, which are once again altering the character of the landscape.

Wheat, barley, gram, cotton and sugarcane are the chief crops grown in the plains area, the latter two predominating in the eastern parts.

1. *Hissar.*

This district falls into four natural divisions:—

A. *The Rohi tract*, of the Sirsa Tehsil which stretches from the northern boundary to the Ghagar, whose soil is a soft reddish loam, interspersed with sand and clay, the water level in the wells of which varies from 40 to 180 ft. in depth.

B. *The Nali tract*, stretching from east to west through the Fatehabad and Sirsa Tehsils. Its characteristic feature is a hard iron clay soil, which permits of no cultivation unless well saturated with water.

C. *The Bagar tract* stretches from the south and west of Sirsa through Sirsa, Fatehabad, Hissar and Bhiwani. Here the prevailing features are a light sandy soil with shifting sand hills interspersed in parts with firmer and even loamy bottoms; the spring level is more than 100ft. below the surface and the water is frequently bitter.

D. *The Hariana tract* comprises the whole of the Hansi, and the eastern portions of the Fatehabad, Hissar and Bhiwani Tehsils and is traversed by the Jamna canal. The leading feature of the tract is its firm clay soil: sand hills are occasionally found, but the low lying parts are particularly hard and clayey. The spring level is generally below 100 ft. except in canal villages where it rises to within 30 to 40 ft. of the surface.

Samples 91 to 96 and 105 to 109 were taken from the Government Agricultural Farm at Hansi and may be taken as representative of the Hariana tract.

No. 91 is a good average soil and contains a small proportion of *kankar*. In wet weather water remains standing on the surface and in times of draught the crops suffer. The rotation generally followed is wheat-cotton-sugarcane, the average yields being respectively 25, 3, and 40 maunds (of *gur* in the latter case). Sugarcane is manured at the rate of 15 tons of farmyard manure per acre.

No. 92 is a good loam very well drained and is generally put under the rotation, cotton, *juar*, with manure to cotton only. The average yields obtained are 10 maunds of cotton and 10 maunds of *Juar* (*Sorghum vulgare*).

No. 93 is of the same type as No. 92. The rotation followed is wheat, cotton, *senji* (*Melilotus parviflora*) without the use of any manure, and the average yields per acre are, wheat 30 maunds and cotton 12 maunds.

No. 94 is a somewhat poorer soil of average type and contains a very small amount of *kankar*.

Nothing but cotton was grown in this field and no manures were used. The average yield of cotton obtained was 6 maunds per acre.

No. 95 is of the same type as No. 94 except that this soil was from a permanent wheat plot where no manure was used and the average yield of wheat grain per acre was 15 maunds.

No. 96 is a very heavy soil fit for growing rice only, and was rather impermeable to water. No manures were used and the yield of rice averages 15 maunds.

Soils Nos. 105 to 107 have an almost similar chemical and mechanical composition. No. 105. however, was taken from a field which was developing *kallar* and hence is not suitable for growing normal crops ; still, barley and fodder crops do quite well in this soil. No. 106 is a sample of soil from a piece of land which was under the rotation wheat, *toria*, cotton, and represents one of the best soils on the farm. The average yield during the last five years has been 23 maunds per acre of wheat, *toria* 6 maunds and cotton 9 maunds. No. 107 is a sample of soil from grass land on the farm. Samples 108 and 109 are from a plot which was under wheat.

Samples No. 97 to 100 are from the Hissar cattle farm. Hissar may be said to represent the Bagar tract of the district although some of its area falls in the Hariana tract. The sample examined contains a high percentage of clay, but the presence of a considerable quantity of fine sand imparts to these soils the characteristics of a sandy loam. The soil represented by Nos. 99 and 100 are coarser grained than the others and more suitable for wheat, oats and barley. This soil, however, produces good crops of sugarcane and *chari*, when manured.

Samples 101 and 102 represent soil and sub-soil samples respectively from permanent rice fields in the village of Rasulpur (Tehsil Sirsa) and are representative of the soil in that locality. The soil as the mechanical analysis shows is a hard, clayey soil containing 25 per cent. of clay. Nos. 103 and 104 are soil samples from the village Sikandarpur of the same Tehsil which is suitable for growing sugarcane, maize, potatoes and vegetables.

One remarkable feature common to all the soils from Hissar is that their lime content is higher than that of any others of the district, while in regard to the other constituents they are similar to soils from Hansi and Sirsa. Correspondingly, the lime and magnesia ratio is high, in fact, higher than in any of the average soil samples from Hansi, Hissar or Sirsa.

There is one noteworthy feature about the two soils from Sirsa, their lime content is about the same, but magnesium in the soil from Rasulpur is about three times that found in the Sikandarpur sample. This difference reflects itself in the lime magnesia ratio, which becomes 2·23 the highest for any of the soils examined so far in the entire district. At present there seems to be no explanation for this difference : no doubt the soil from Sikandarpur is sandy and that from Rasulpur a heavy medium type, but we do not get lower figures for magnesia in sandy soils as a general rule.

2. *Karnal.*

The soils in this district are of a very diverse character varying from fertile loams to stiff clays which are covered with dense thickets of *Dhak* (*Lutea Frundosa*).

A great portion of the land in the district is watered by the western Jamna canal, while floods from the Saraswati and other streams are helpful in raising crops such as gram from the area commanded by them. The figures for two samples of soil from the well irrigated areas of the district are given under Nos. 110 and 111 of Table I. Sample No. 110 was taken from a plot in Samalkha and is best suited for growing wheat. This soil, with sub-soil water 13 ft. below the surface, is very well drained, and yields on an average 20—25 maunds of wheat per acre. The general rotation practised is wheat, sugarcane, wheat. Sugarcane is generally manured at the rate of 20 cart loads of farmyard manure per acre, but wheat is seldom manured. The yield of sugarcane is 40 to 50 maunds of *gur* from the Suretha and Lalri varieties. Sample No. 111 was taken from the village Manana, where sugarcane is the chief crop grown, yielding an average of 50 maunds of *gur* per acre. The rotation followed is sugarcane, wheat, cotton, *senji*. Both sugarcane and cotton are manured, the former at 20 - 25 cart loads per acre and the latter at 12 - 15 cart loads only. The new varieties of sugarcane such as Co. 205, 223 and 213 are now giving much higher yields, *viz.*, about 80 maunds of *gur* per acre. The soil is good and well drained and carries a hard clay substratum at about the 7th foot, while the depth of the sub-soil water is about 19 ft. Other analyses of soil samples received from the Deputy Commissioner of the Karnal district in the year 1914 are given under Nos. 112-118.

Nos. 119 -121 are samples of surface soils and sub-soils from the Imperial Cattle Breeding Farm, Karnal, having been taken respectively from plots Nos. 3, 4 and 5. No. 125 is from plot No. 2. As will be seen from the analysis, the soil of the farm is a light medium loam, and, as experience has shown, gives a very good crop of wheat, the average yield being 20 -25 maunds. These soils can with proper manure and irrigation be made to yield very good crops of sugarcane, the climatic conditions for which are very suitable, owing to the absence of frost.

3. *Ferozepur.*

This district consists of a flat alluvial plain well wooded in its northern half, but very bare in the south where it is absolutely without hill or eminence of any description and devoid of rock and stone.

Wheat and gram are the most important crops, rice and maize being grown on the inundation canals, while *Moth* (*Phaseolus aconitifolius*) is the chief crop of the sandy tracts. Little sugarcane or cotton is grown. A large portion of the district has recently come under irrigation, by waters from the Sutlej valley canal projects.

Sample No. 126 in Table I was obtained from a tract commanded by both inundation canals and well irrigation in Ferozepur Tehsil. Water percolates with

difficulty and on drying the land becomes rather hard. It is usually put under wheat and gives an average outturn of 20 maunds per acre. The spring level is generally about 10 ft. from the surface.

Sample 127 was obtained from a village, Sada Singhwala in the Moga Tehsil, whose land is irrigated by canal water and is generally put under gram, although a study of its physical constituents and chemical analysis indicates that it is suitable for more paying crops.

Samples Nos. 128—131 were obtained from the Military Dairy Farm, Ferozepur cantonment and represent light medium soils quite well suited for growing sugarcane, wheat and gram. Nos. 128 and 129 are the surface soil and sub-soil samples from plots 5, 6 and 7 on the farm which are under wheat, gram, barley and oats. Samples Nos. 130 and 131 represent soil from plots 3 and 4 which is not so sandy and grows maize, *chari*, barley and lucern.

4. *Jullundur.*

This district forms an irregular triangle with its base on the river Sutlej. No hill or rock breaks the monotony of the plain which forms a zone of rich cultivable soil skirting the foot of the Himalayas and was regarded by the Sikhs (before the present canal system came into existence) as the garden of the Punjab. Sandy patches are found at places, and with these few exceptions one vast sheet of luxuriant and varied vegetation spreads over the plain from end to end. A complete failure of the rains seldom occurs, and, assisted by the protection afforded by the numerous wells, the soil is on the whole sufficiently charged with moisture to resist minor attacks of drought. A large portion of the district consists of good alluvial loam; though patches of clay and sandy soils also exist. Tracts are also known which contain a considerable quantity of large nodules of *kankar* in the sub-soil layers.

The only analyses available are from samples obtained from Rahon, near the eastern corner of the district. Samples 132 and 133 in Table I show the analysis of these soils. No. 132 was taken from a light soil, while sample 133 represents a very fertile heavy loam. The chief sources of irrigation are wells and flood water from the river. The average yields of crops from these heavy soils per acre are :— wheat 15 maunds, cotton 5 maunds, maize 12 maunds, and rice over 20 maunds. In the absence of irrigation facilities, the sandy soils are seldom put under crops.

No. 133 is the heaviest fertile soil in the Province we have met with. The average rainfall in the locality is 20 to 30 inches and it is quite probable that such a soil, if situated in arid tracts like that of Multan or Muzaffargarh, might prove to be quite uncultivable and unfertile. This is an illustration of the fact that climate and locality very largely determine the properties and character of any soil.

5. *Lahore.*

The Lahore district presents an almost uniform level surface from end to end, with hardly any variety in its physical features. Its soil is inclined to be dry, but

in parts near the Amritsar border good sandy loams are met with. The well waters specially in the tract between Patti, Kasoor, Raewind and Kana Kachha are inclined to be saline.

Two samples of soil from this tract are on record. No. 135 in Table I was taken from a village named Jodhu in the Lahore Tehsil. It is a very good soil, well drained, and is generally put under a heavy cropping system, the chief rotation followed being wheat cotton *senji*-sugarcane.

Sample No. 136 was taken from the District Board farm at Raewind and is fairly representative of the saline tract mentioned above. The soil is very fertile and grows good crops of wheat, maize and sugarcane. The sub-soil water is generally at a depth of about 20 ft.

6. *Sheikhupura.*

This district is a new one having been until quite recently a part of the Lahore, Gujranwala, Sialkot and Lyallpur districts.

Most of the land in the district is irrigated by the Upper Chenab Canal and the Lower Chenab Canal, and on account of seepage of water from these canals, a vast tract of land near Chichoki Mallian has become waterlogged and consequently unfit for cultivation. Rice is the chief crop grown in the greater part of the district.

The eastern tracts of the district have another source of irrigation in the river Degh which, rising in the Jammu hills and flowing through the districts of Sialkot and Gujranwala, enters Sheikhupura district at its extreme north-eastern border near Sadhoke and continues for most of its course to flow parallel to the eastern boundary of the district. At Tappiala it branches into two portions, one portion borders the large village Kot Pindi Dass and the other Kuthiala and Khanpur. The latter branch is called the chhoti Degh. They again join near the village Dhenga and after flowing for some miles further, the stream falls into the Ravi. The Degh is most uncertain in its supply of water, being principally dependent on the rain from the hills. At times, however, the stream descends with great rapidity, and its waters overflow the country for miles on either sides. In the hot weather it is nearly, but very rarely, quite dry. Above the village of Uderi the water has to be raised by Jhalars of Persian wheels, but below it irrigation can be effected by the natural flow of the water. The deposit left by the flow is rich and the best rice is grown on lands which have been submerged by it.

No. 137 in Table I is a sample of a very good soil which generally gives an outturn of 15—20 maunds of wheat, 6—9 maunds of cotton, 30—40 maunds of sugarcane (*gur*) and 12 to 15 maunds of *toria* (*Brassica Napus*).

No. 138 is a sample from a soil which represents a fair average of the tract. The average yields obtained on this tract of land are from 12—15 maunds of wheat, 5—6 maunds of cotton, and 8—10 maunds of *toria*. Sugarcane is seldom grown.

Samples Nos. 139 to 150 are from different types of soils but all growing wheat under different conditions of irrigation; these being recent canal irrigation, old

canal irrigation, *barani* and well irrigation. Each successive set of 3 soils representing sandy, loam and clay, being under the above mentioned four types of different irrigations respectively. A glance at the figures of analyses will show that no correlation appears to exist between the chemical analayses and any particular type of soil.

The water level is generally 27 to 30 ft. from the surface.

7. *Gujrat.*

The Northern corner of this district is crossed by the Pubbi hills, a low range forming a continuation of the salt range and pierced by the Jhelum at Mung Rasul. Immediately below and surrounding these hills, a high sub-montane tract extends across the north of the district from the Jhelum eastward. But the greater part of the district lies on the Indo-Gangetic alluvium. The sub-montane portion consists of a good firm soil of reddish colour with an admixture of sand. The portion in the plains, however, consists of a rich reddish loam.

Samples Nos. 150, 151, 152 were obtained from Chillianwala and represent soils which are chiefly suited for sugarcane, gram and rice respectively.

5. The North-West dry area.

1. *Montgomery.*

This district occupies a great part of the tract known as the Ganji Bar.

The land in the two Tehsils, Montogomery and Okara, with the exception of a small tract near Kamalia, is irrigated by the Lower Bari Doab canal, while the Depalpur and the Pakpattan Tehsils are irrigated by water from inundation canals supplemented by water from wells. During the next few years, however, it is expected that the whole of the district will come under irrigation from the Sutlej valley project and the proposed extension of the Lower Chenab Canal. The soils of the district comprises some very good loams and also some very hard soils quite unfit for cultivation. Soils impregnated with soda and other salts are not uncommon.

The Agricultural Department possesses an experimental farm at Harrappa where the problem of reclaiming *bara* soil is under investigation. Some description of these inferior soils will be given later. Confining attention for the moment to the good soils in Table I, samples 153—157 represent specimens of normal soils of the district. Cultivation of these lands has been of a very recent introduction (the canal having been opened as recently as 1914) and they are capable of producing very successful crops of American cotton. *Desi* cotton, wheat, sugarcane, *toria* and maize.

Samples Nos. 158—162 are from the Coleyana Estate, Okara. Nos. 158 to 161, from squares 25, 26, 43 and 45 respectively, are specimens of good sandy soils suit

able for lucerne and *oats*, but equally suitable for growing charree, shaftal and other cereal crops. No. 162 is a sandy soil approaching a medium loam, and is one of the best soils on the estate.

Soils Nos. 163 to 166 are from the Agricultural Department's old Seed Farm, and 167 to 172 from the new Seed Farm. Nos. 163 and 164 are the soil and sub-soil samples from square 17, line 1, and 165 and166 from square 15, line 3. On the basis of their mechanical analysis, both these soils (Nos. 163 and 165) belong to the group of sandy soils; but since almost all the sand present is fine sand, the soils approach the medium loam type which is suitable for growing almost all crops. The 6 samples, Nos. 167- -172, are the soil and sub-soil samples from square 15 field 11, square 28 field 1 and square 12 field 25 on the new seed farm. The first of these resembles in texture soil Nos. 163 and 164 above, while the last is a light medium soil.

2. *Lyallpur.*

The district was constituted in 1904, mainly from villages transferred from Jhang, with the addition of a certain number from Montgomery. It comprises most of the high table land between the Chenab and the Ravi rivers and is now irrigated by the Lower Chenab canal. The climate is very hot in the hot season and the rainfall very low, *viz.*, about 12 inches. The sub-soil water is very low, about 58 ft., but has been steadily rising in recent years. The soil is a fine loam, except in the Toba Tek Singh Tehsil where it becomes sandy towards the west.

From 8 to 10 ft. below the surface, the sub-soil is extremely sandy, hence the soil is very well drained and water percolates with considerable ease. The water level is about 60 ft. from the surface and has risen about 3 ft. during the last ten years.

Several borings have been made extending to the sub-soil water level in connection with work on the movement of moisture in the Lyallpur soils. Table III shows the figures for the mechanical analysis of each successive 2 ft. column of soil. A glance at the figures obtained from these borings will show how very sandy are the lower strata of the sub-soils in the Lyallpur district.

Other analyses of soil samples obtained from the Government Agricultural Farm at Lyallpur and other parts of the district are presented in numbers 174 to 185 of Table I. Nos. 182 to 185 are surface soil and sub-soil samples from square 10 and 29 respectively on the Lyallpur Agricultural farm. Both these soils are sandy, the former being a comparatively poor soil having been under various crops, such as barley, wheat, oats, during the last five years. The latter represents soil from the Botanical garden which has been found to be very well suited for growing citrus trees, mangoes, dates and other fruits.

No. 173 may be considered to represent a typical soil of the district. From an inspection of the analyses of other samples, it will be seen that the soils of this district are of a distinctly sandy nature, lacking in humus, but successfully produc-

ing cotton, wheat, sugarcane, *toria* maize, vegetables and fodder crops. The chief rotations followed are:—

1. wheat, wheat-*toria*, cotton.
2. wheat, cotton, wheat.
3. maize, *senji*, sugarcane, wheat.
4. wheat, *chari* and *guara*, gram, cotton.

The average yield for these crops are:—

Wheat:—16 maunds, *toria* 8 maunds, cotton 8 maunds, maize 16 maunds, *senji* (green) 250 maunds, gram 20 maunds, sugarcane 50 maunds (*gur*), *chari* and *guara* (green) 300 maunds.

Oranges, lemons and maltas have also done particularly well.

It has been estimated that alkali land to the extent of about 175 square miles exists in this district representing, from absence of cultivation, a loss of about Rs. 100,000 annually in revenue alone.

3. *Shahpur.*

With the exception of that portion of the salt range which is included in the north of the Khushab Tehsil, the whole of this district forms part of the great Indo-Gangetic plain.

In the valleys of the Jhelum and the Chenab, and in the plain between, the soil for the most part is a very fertile sandy loam interspersed with patches of clay and sand. The portion covered by the Thal consists chiefly of sand hills with occasional patches of hard level soil and tracts of ground inpregnated with salt on which practically nothing grows.

In Table I, Nos. 186, 187 188, 190 to 196, and 206 to 213 were obtained from the Sargodha Remount Depot, soil No. 186 being particularly good for growing wheat; cotton does best on No. 187, and No. 188 responds very well to sugarcane. In fact, Nos. 187 and 188 would, under the circumstances, grow good crops of wheat, cotton, sugarcane, maize and *toria*.

Soil No. 189 is from the Camel Corps Farm, Sargodha, and is deficient in nitrogen and phosphates. The analyses shows that soils Nos. 190 to 196, reported as poor, are not deficient in plant food but require proper cultivation. No. 194 is, however, calcareous and poor in phosphoric acid.

Samples Nos. 206 to 213 represent the surface soil and sub-soil samples from 4 different places on the farm. Samples 206 and 207 are specimens of a light medium soil from square 366, under the rotation, *chari*, fallow, linseed and oats. Samples 208 and 209 are from square 207, a type of medium soil bordering on heavy loam. This is the heaviest soil on the farm and one of the best as far as yield is concerned. The rotation generally followed is berseem, oats and lucerne, sugarcane, wheat and cotton; in fact, all kinds of crops should do equally well. Samples 210 and 211 are from square 64 and represent a light sandy soil suitable for growing gram,

barley, etc. The rotation followed has been gram, barley, (*Guara* as green manure), barley and *chari*. The last two samples from the farm are from permanent grass plots used for grazing and making hay and represent a medium silt soil, one of the best types of soil from an agricultural point of view.

Samples Nos. 197 to 205 were taken from the Remount Depot, Mona and represent all the different types of soil met with on the Depot area. Soils Nos. 197 and 198 are the surface soil and sub-soil samples from square 72 which comprises a medium silt soil capable of growing oats, barley and citrus fruits, etc. The rotation actually followed on the area is, *chari*, fallow, lobia, fallow, oats, fallow. Soils Nos. 199 and 200 are specimens of a medium soil with a high percentage of clay but considerably modified by the presence of a considerable admixture of sand. The area has been kept under grass, but the soil is of a quality such as to be well suited for wheat, oats, *chari*, lobia, etc. In samples 201 and 202 (square 33) we have a light sandy soil which should do quite well for *moth*, barley, gram, etc. Samples 203 and 204 (square 125) represent a soil similar to that of Nos. 197 and 198. It should grow all the crops for which the previous soil is suitable; as a matter of fact, it is used as a permanent grass paddock. Soil No. 205 is the first foot sample from square 165 which is under lucerne.

4. *Jhang.*

The district is divided into 3 portions, *viz.*—

(*a*) *The tract lying toward the east of the Chenab River.*

The soil here is an alluvial loam more or less mixed with sand, and, on the whole, extremely fertile, and is commanded by the Lower Chenab Canal.

(*b*) *The Tract lying between the Chenab and the Jhelum.*

This is irrigated by the Lower Jhelum Canal and the soil is generally good except that in many places it is impregnated with salt and therefore unfit for cultivation.

(*c*) *The portion lying west of the Jhelum.*

This is a portion of the famous tract known as the Thal. The Great Indian Desert, which borders the whole southern limit of the province sends out two arms which embrace the actual country of the five rivers. That on the east takes in a great part of the Phulkian state, with its apex near the town of Ludhiana. The western arm (locally known as the Thal) extends from the Sind border up the Indus valley to the south-west angle of the salt range. The eastern chain of sand-hills and alternating barriers has of late, however, lost much of its desert character through canal extensions. The Thal which constitutes the great Stappe in the Sind Sagar Doab, consists of a series of rolling sand-hills formed by the wind, which

run parallel to the great barrier formed by the salt range and are broken by valleys in which the original surface is exposed. In some of the eastern parts of the Thal the sand hills are very high, in others the ground is perfectly level for miles. A scanty rainfall, a treeless sandy soil, and a precarious and scattered pasturage mark this out as the most desolate tract now remaining in the Punjab. Much of it is real desert, barren and lifeless, and devoid not only of bird and animal life but almost of vegetation.

Nos. 214 and 215 in Table I show the analyses of samples of soils from a village, Bagh, in the canal irrigated tracts of the district. Containing as they do an excess of coarse and fine silt, they form very good soils for crops such as wheat and cotton.

5. *Multan.*

The Multan district is almost entirely encircled by the confluent streams of the Chenab and the Jhelum which unite at its south-western extremity. The soil of the district is of a uniform alluvial nature, with sand everywhere at a greater or less depth from the surface. From an agricultural point of view, the district may be regarded as composed of 3 distinct tracts :-

(*a*) The riverain tract.

(*b*) The tract irrigated by the Lower Bari Doab canal and the inundation canals and wells.

(*c*) The *Bara* (unirrigated).

In Table I. sample No. 216 represents a soil from the tract irrigated by the inundation canals and wells. while sample No. 217 represents a good soil from the area covered by the Lower Bari Doab canal. Analyses of samples from other parts of the district are given under Nos. 218 - 229, of the same table.

6. *Muzaffargarh.*

This district occupies the southern area of the Sindh Sagar Doab. The wild Thal of the Doab extends as far as the middle of the district and occupies more than half of its area. A brief description of the characteristics of the Thal has already been given.

Of the remaining land, that lying alongside the two rivers is subject to heavy floods, but the central portion is protected by embankments and is within easy reach of irrigation facilities. This portion accordingly is rich and productive and many large and prosperous villages are to be found in it.

Samples Nos. 230 and 231 in Table I have been taken from the irrigated tracts of the district where irrigation conditions are favourable. Most of the soils, of which sample No. 230 is typical, are put under rice. Otherwise, the soils taken as a whole also produce very good crops of wheat and cotton. Lately, however, considerable attention has been paid by the Zamindars to the development of fruit trees such as the date palm, mangoes, pomegranates, etc., and it is hoped that in

the near future this portion of the Muzaffargarh district will be more particularly devoted to fruit growing, specially the date palm, for which, owing to the saline nature of the soil, it is better suited.

Salt incrustations are common in the Muzaffargarh Tehsil.

7. *Dehra Ghazi Khan.*

This district is situated to the west of the Indus. On the north side it is mountainous, but the greater part of the district lies on the alluvium of the plains.

The soil varies from a rich loam to an alluvial clay as we pass from the mountains to the Indus. The chief sources of irrigation are the inundation canal from the Indus, and hill torrents which also deposit large quantities of silt, thus adding to the fertility of the soil.

Sample No. 232 in Table No. I was taken from a village named Churatta. The land is well drained and has a sub-soil layer which is very sandy. The chief rotation followed is wheat, *chari*, or wheat, cotton, and an average outturn of 10 maunds of wheat and 5 maunds of cotton per acre is obtained.

Samples No. 233 was taken from a village named Paigan. This and the village Churatta are both situated in the area irrigated by inundation canals and wells.

This land is considerably better than that represented by No. 232 and usually yields a crop of about 12 to 15 maunds of wheat and 5 to 6 maunds of cotton in a rotation of wheat followed by cotton.

6. The Mechanical Analyses.

Table I gives the results of the mechanical analyses of 139 surface soils and 54 sub soil samples representing most of the districts of the Punjab. These results are represented on diagrams 2 7 which are drawn in accordance with Wilsdon's modification of the American system [1 and 2]. A glance at diagram 2 shows that most of the Punjab soils examined fall within the area represented by sandy loams and medium loams, although a fair proportion are clay loams. There are very few samples representing clay, sand and silt soils. Thus the majority of the Punjab soils tend to fall into groups (described by Hall as light loams and heavy loams), which, so far as the mechanical composition is concerned, are ideally good soils for cultivation, being good loams, sufficiently retentive of moisture and not difficult to work, and which should produce any type of crop provided proper manure is given. The general inclination of the Punjab soils is towards light sandy soils (medium soils) rather than clays, and as such they are one of the best types from the points of view of soil aeration, cultivation, and other factors so necessary for

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[1] Whittles, C. L. A note on the classification of soils on the basis of mechanical analysis. *Journ. Agri. Science*, Vol. XII Pt. 2.

[2] Wilsdon, B. H. The need and objects of a soil survey in the Punjab *Agric. Jour. India*, Vol. XIV, Pt. II, 1919.

DIAGRAM II

showing

DIFFERENT TYPES OF THE PUNJAB SOILS ACCORDING TO THEIR MECHANICAL COMPOSITION

(THE NUMBERS IN CIRCLES CORRESPOND TO THE NUMBERS IN TABLE I)

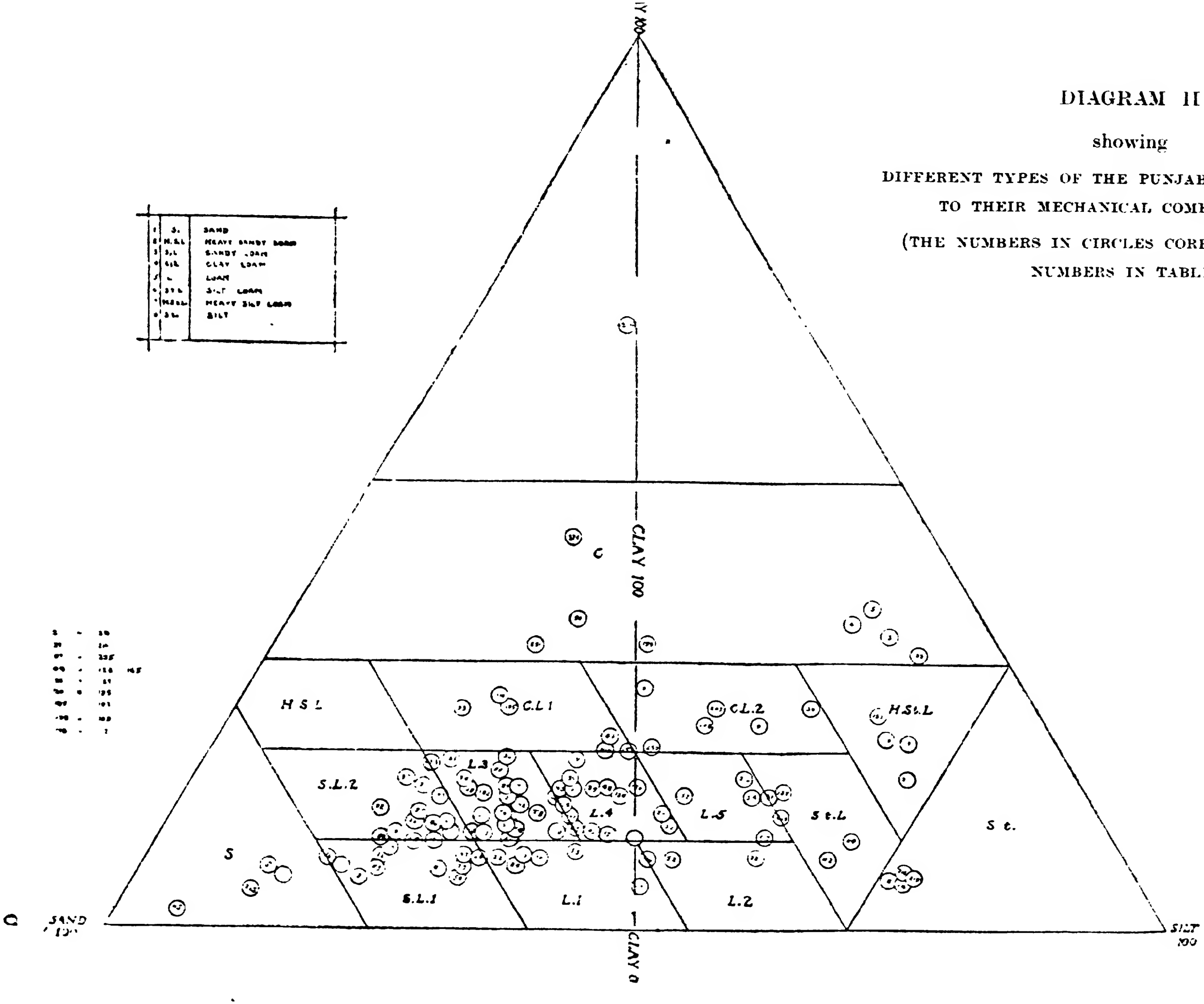


DIAGRAM III

showing

WHEAT SOILS

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

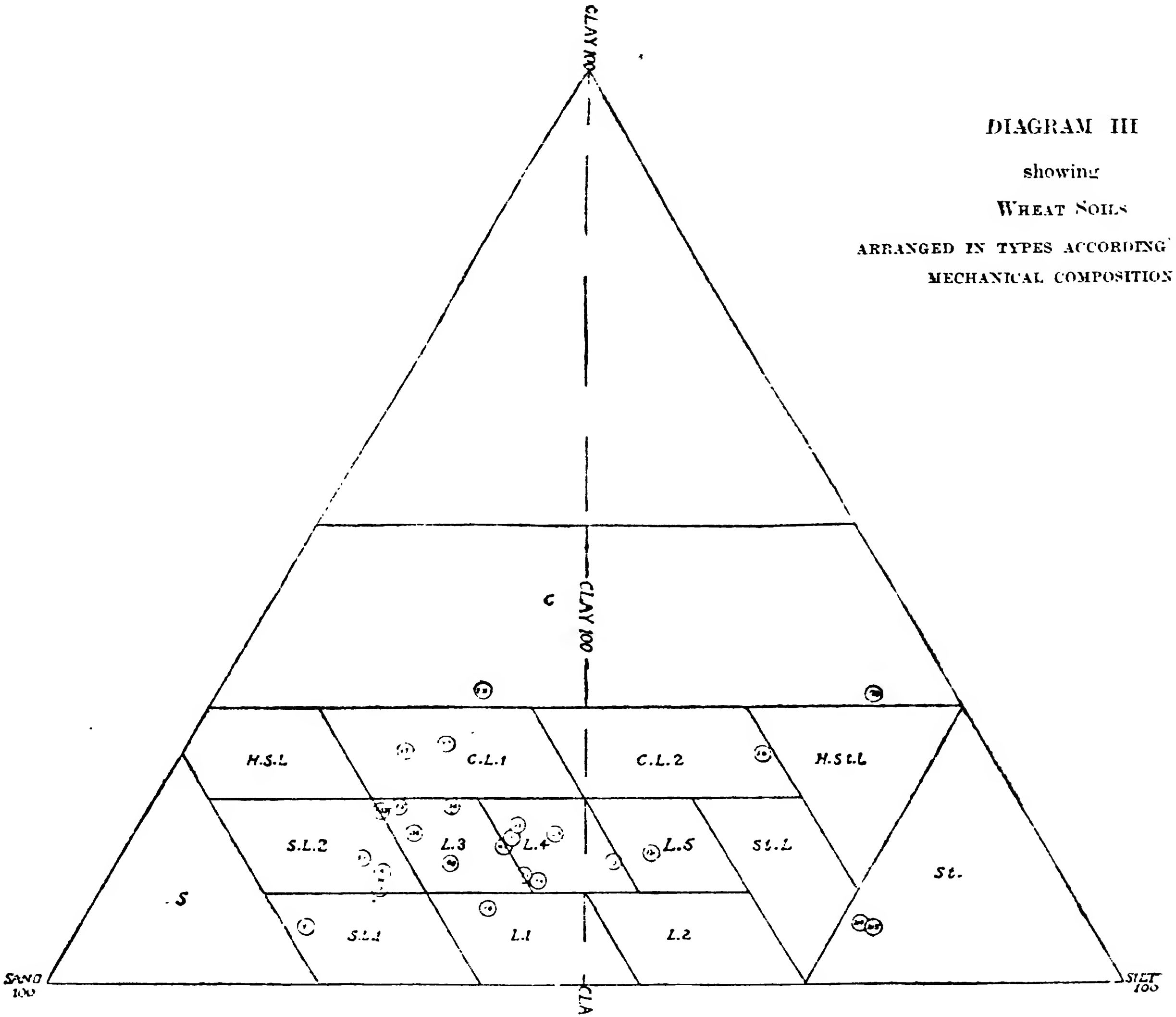


DIAGRAM IV

showing

Cotton Soils

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

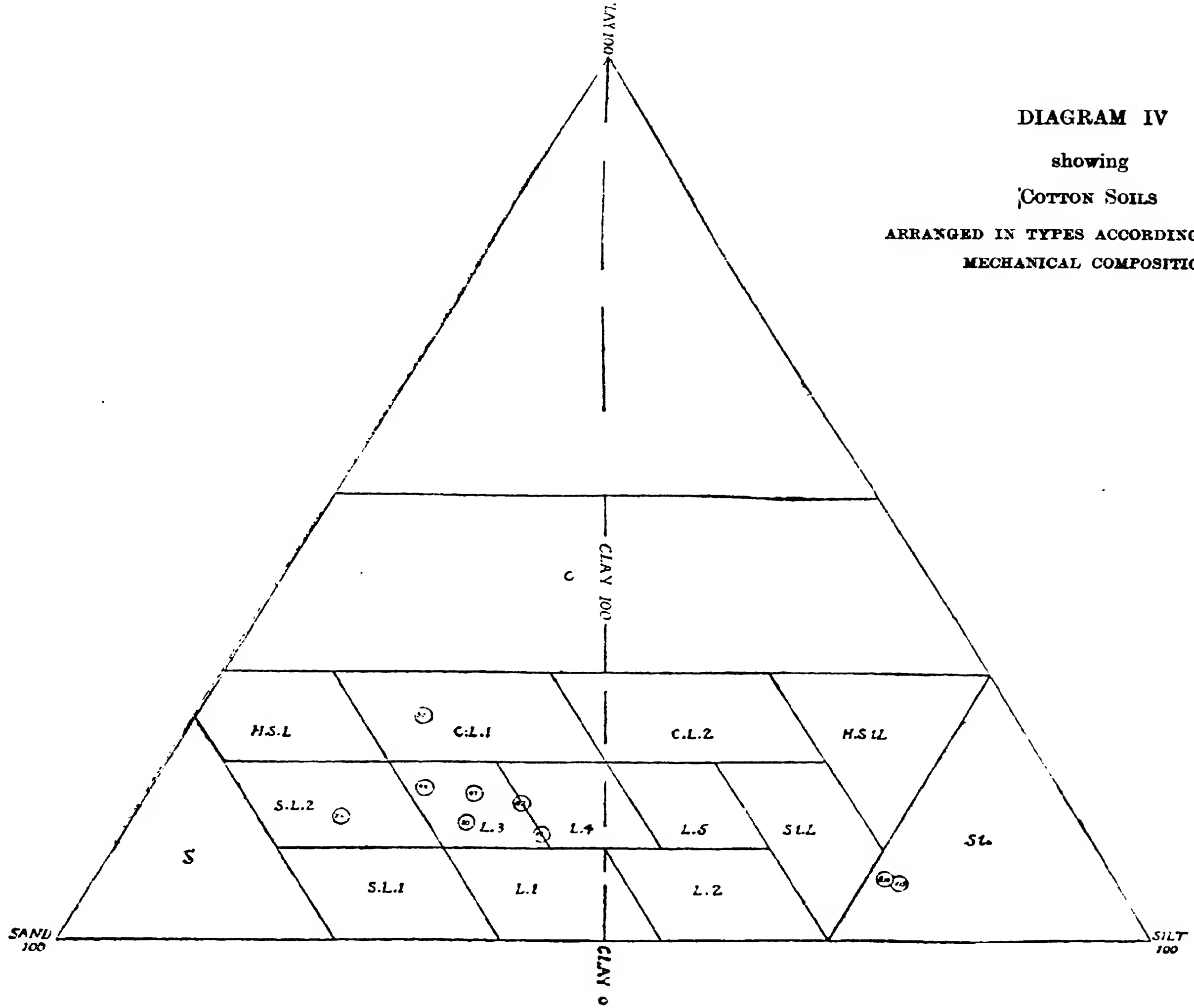


DIAGRAM V

showing

SUGAR CANE SOILS

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

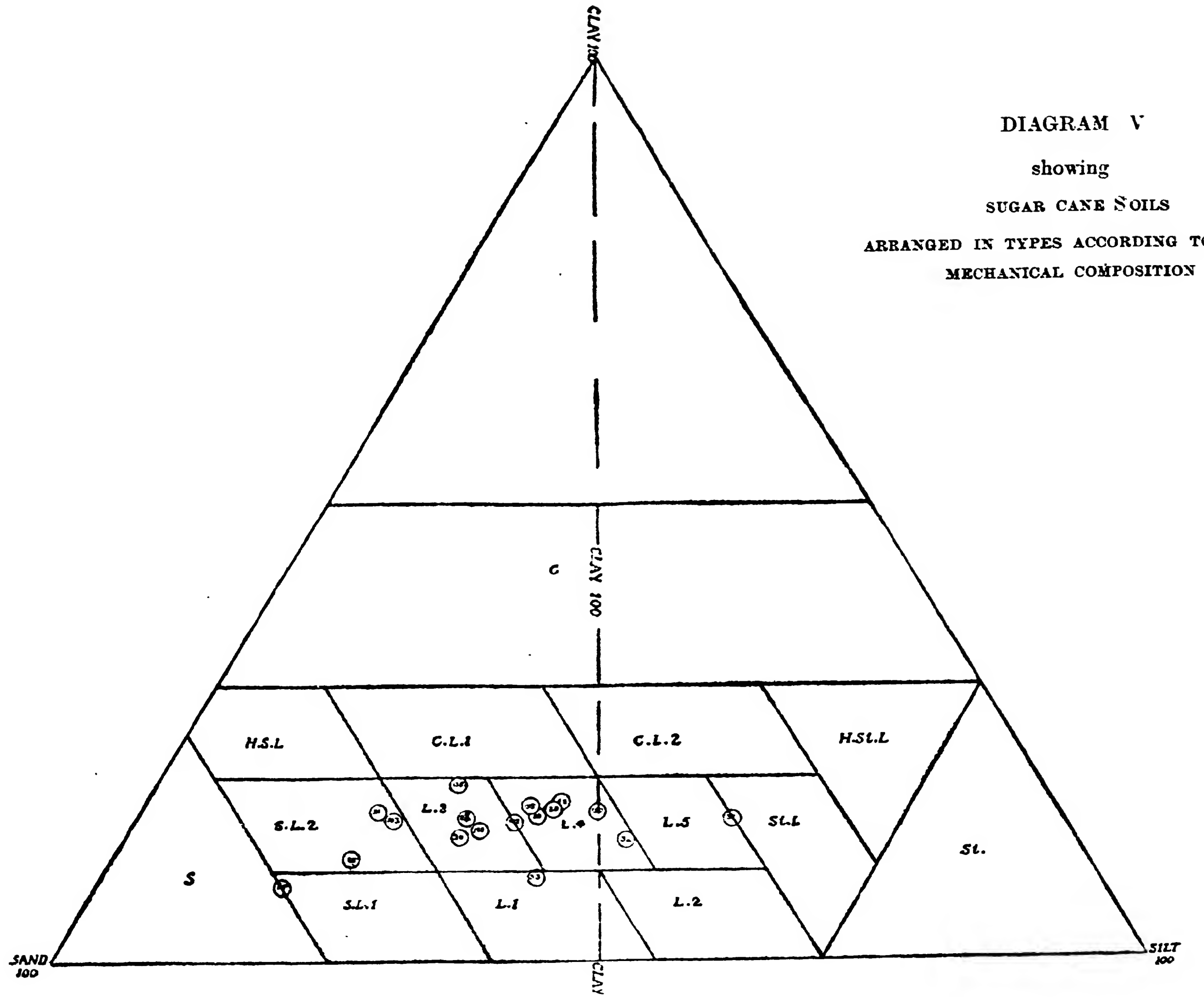


DIAGRAM VI

showing

RICE SOILS

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

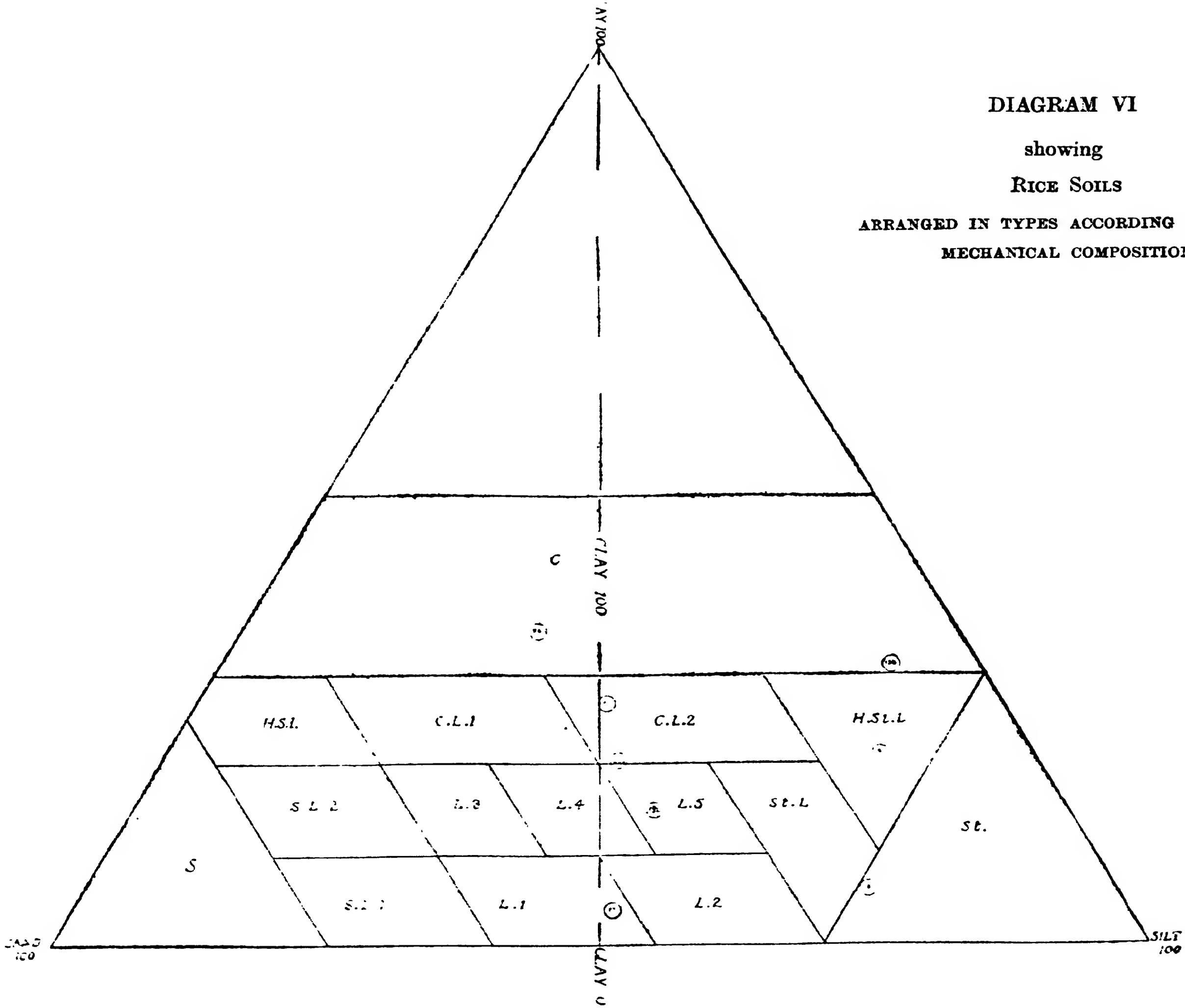
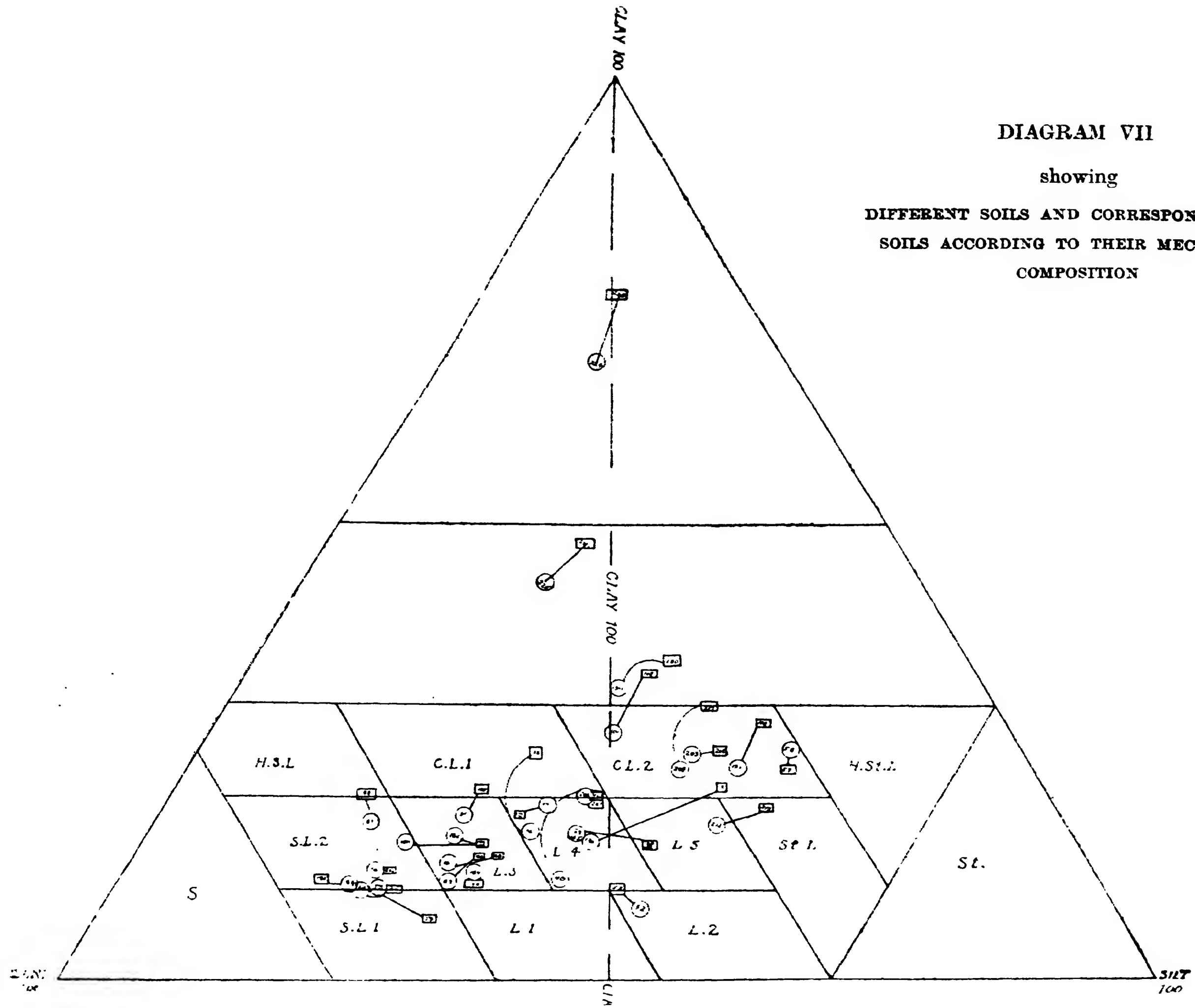


DIAGRAM VII

showing

DIFFERENT SOILS AND CORRESPONDING SUB SOILS ACCORDING TO THEIR MECHANICAL COMPOSITION



successful farming. Most of the soils have a clay content lying between 10 per cent. and 20 per cent. although quite a large number are known with a clay content much less than this—in some cases as low as 2-3 per cent. and sand as high as 70—80 per cent. It might appear that these latter soils are unfit for profitable farming, but as already mentioned the mechanical texture of a soil must also be considered in terms of rainfall, water supply, organic matter present, and other factors. A soil of a certain mechanical texture behaving as a loose sandy soil in a district with deficient rainfall (say in Multan or Muzaffargarh) may behave as a loam in a district with a medium rainfall, and as a heavy loam in a district with a heavy rainfall (*e.g.*, Kangra). Soil No. 1 from Kangra, for instance, is a sandy soil and Nos. 3 and 4 clay soils, but all of them are very good tea garden soils. A reference to the map showing the rainfall of the Province will demonstrate that most of these soils are quite suitable for profitable cultivation in districts such as Ambala, Hoshiarpur, Jullundur, Gurdaspur, Kangra and Simla. With plenty of organic material available, these sandy loams can readily be made to produce very profitable crops.[1]

At the two extreme ends of the scale we have samples Nos. 1 and 225. The first one is a sample of a sandy soil from Kangra containing only 6 per cent. of clay and 14 per cent. of silt, while the second one represents the heaviest soil so far net with containing 70 per cent. clay. These two samples demonstrate the effect of sand and clay on soils when these are present in abnormally high quantities. While it is possible, by suitable means, to raise crops from sandy soils, it is hopeless to expect any very good results from soils containing 50 per cent. or more of clay. Soil No. 1 grows a very good crop of tea, while soils Nos. 224 and 225 are unsuitable for growing even grass; nothing but sparsely scattered, dry parched shrubs grow upon these.

7. The Chemical Analysis.

1. *Nitrogen.*

Before attempting to discuss the nitrogen figures presented in Tables I and IV, it may be pointed out that experiments have been in progress both in the field and in the Laboratory at Lyallpur to find out the amount of nitrogen fixed in the soil and the factors that are responsible for the fixation. The results obtained have already been published [2], [3], [4], [5] and from them it will be seen that soils in

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[1] Lander, P. E.; Wilsdon, B. H.; & Mehta, M. L. A study of the factors operative in the value of green manure. *Agri. Res. Institute, Pusa, Bull.* 149, 1923.

[2] Lander, P. E. The Experimental Sullage Farm, Lyallpur, Bull. No. 157. *Agri. Research Institute, Pusa.*

[3] Lander, P. E. Report on the operations of the Dept. of Agriculture, Punjab, for the year ending 30th June 1923, Part I, pp. XX.

[4] Lander, P. E., and Barkat Ali. Nitrogen fixation in the Punjab. *Memoirs of the Dept. of Agri., Pusa, India, Bact. Series* Vol. II, No. I, 1925.

[5] Wilsdon, B. H., and Barkat Ali. Nitrogen fixation in the Punjab. *Soil Science*, Vol. XIV, 1922, No. 2.

the Punjab are capable of fixing nitrogen very rapidly and to as high an extent as 75 per cent. or in certain cases even 100 to 200 per cent., although losses to the extent of 25 to 40 per cent. due to denitrification have also been found. The largest and most frequent losses have been found to take place in the month of August, and this is confirmed by the results given in the report on the sullage farm at Lyallpur. From the curve presented in this report, it will be seen that in the month of August there is a loss of nitrogen to the extent of 600 lb. per acre. At Rothamsted samples of soil were taken every two hours for the estimation of nitrogen and it was found that something approximating 80 lb. of nitrogen was fixed in a single day but subsequently lost in the evening. It would appear therefore that the time of taking samples of soil for analysis will very greatly influence the amount of nitrogen found and in discussing nitrogen figures it is important to keep these fluctuations in mind.

From the data presented in Table IV, it will be clear that the nitrogen content of the Punjab soils, with very few exceptions, falls within the limits of 0·025 per cent. and 0·100 per cent. although most of the soils presented have a figure higher than 0·04, the average of 166 samples being 0·06 per cent. Figures as low as 0·01 (No. 115) and as high as 0·16 (No. 133) may also be noticed. The nitrogen content of the sub soils is slightly lower, the average figure being 0·05 per cent. A reference to the literature on the soils of the Hancock County of the U. S. A. and of Kent and Sussex in England [1], [2], will show that the nitrogen content varies from 0·15 to 0·45 in the soils of Kent and Sussex and from 0·10 to 0·25 in the soils of the Hancock County. This means that the Punjab soils are 50 to 200 per cent. poorer in nitrogen than those of the above-mentioned countries, although most of the soils of the southern states of the United States of America fall within the same range of nitrogen content as do the Punjab soils.

2. *Organic Matter* (*Loss on ignition*).

The Punjab soils taken as a whole are deficient in organic matter. The average of 120 samples works out to 3·75 per cent., while figures as high as 10 per cent. or even more are given by certain soils, *viz.*, from Attock. Most of the Punjab soils contain 2 to 4 per cent. of organic matter. Similar figures for soils from Kent, Sussex and North Wales[3] lie between 2·62 to 14·21 per cent., while for American soils they lie between 2·6 to 9·27 per cent.[4] The red river valley (America) soil contains no less than 26·3 per cent. organic matter.

In Table IV the ratios of the nitrogen content to the loss on ignition of the majority of soils in the Punjab are given. It will be observed that with very few

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[1] Smith, R. S. Hancock County Soils. *Soil Report* No. 27. Agricultural Experimental Station, Illinois University.

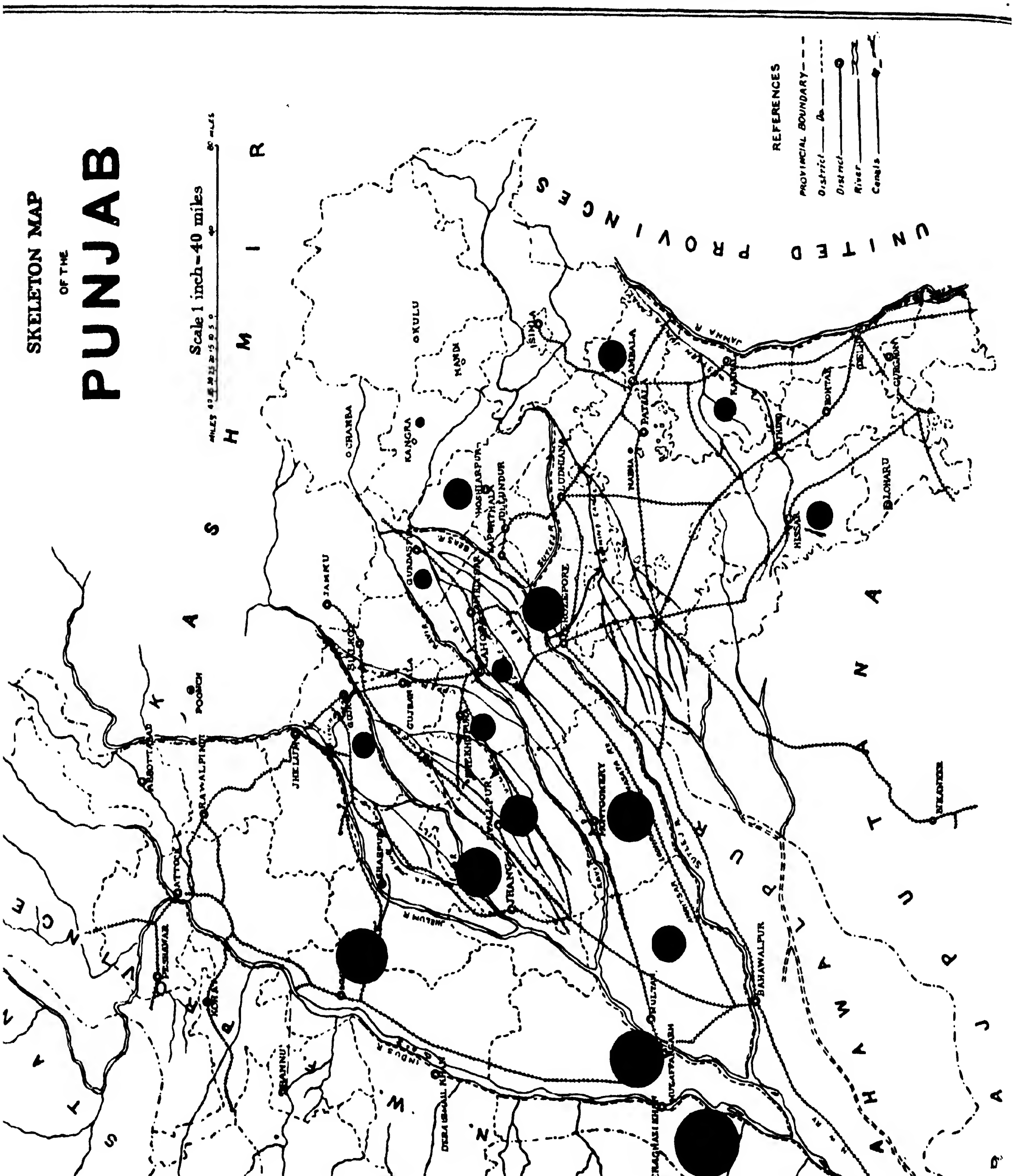
[2] Russel, E. J. Modern applications of Chemistry to crop production, 1922.

[3] Robinson, G. W., and Hill, C. F. Further studies on the soils of North Wales. *Journal Agricultural Science,* Volume IX, 1919.

[4] Robinson, G. W. Variations in the Chemical composition of Soils. *U S. A. Deptt. Agri. Bull.* 551, 1917.

DIAGRAM VIII.

Showing, lime centent of soils from different districts of the Punjab.



exceptions (which may partly be due to errors introduced in certain cases in the determination of this figure), the ratio falls between 0·01 and 0·02, *i.e.*, nitrogen constitutes from 1 to 2 per cent. of the loss which occurs on ignition of the Punjab soils.

3. *Lime.*

The manifold functions of lime in the soil render the question of the lime content very important. It not only keeps the soil in a flocculant condition and helps in the decay and nitrification of organic matter, but also preserves the soil flora against fungoid diseases and exercises considerable influence in the selection of manures. Diagram VIII represents graphically the quantity of lime present in some of the districts of the Punjab. It is based upon the limited number of soil samples so far examined which in some cases are far from sufficient to justify one in striking an average, while in others though the number is not very small—the soils have been taken from but a limited number of localities in the district and hence are not representative of the whole tract. They are, however, represented in the diagram as indicating a possible method of classification or interpretation, but the diagram will undoubtedly require considerable modification as more data accumulate. The black circle indicates the amount of lime present in soil from a particular district in terms of relative average percentages. It will be seen that with the exception of Ferozepur there appears to be a tendency for the lime content to increase progressively from the Himalayas to the south-west. One may note here that Barnes and Barkat Ali[1] observed that the ferrous iron held in solution in the sub-soil water progressively increased from the surface downwards, and also with the distance from the Himalayas. It is apparent from the diagram that the curve of increasing lime content follows the course taken by the rivers in the Punjab, the soils in the north-west dry area being much richer in lime than the soils in the trans-Gangetic plain or even in the sub-montane tract. The soils from the hilly tracts of the Kangra district show but a very small percentage of lime, and it would be interesting to note if the soils from other hill districts show corresponding features. At present the only other soils from hilly tracts examined are those from Attock, but these, as we have already pointed out, are quite abnormal.[2]

It may be argued that the soils situated in the north-east of the Punjab are deficient in lime. This, however, is an assumption which needs qualification for the following reasons :—

1. The samples examined were all taken from plots which represent good fertile portions of the tract and were giving good yields of crop, which compared favourably with those raised in earlier years.

[1] Barnes and Barkat Ali. Chalybeate waters from tube wells in the Punjab ; their significance to the municipal Engineer and to manufacturer. *Agricultural Jour. of India*, Vol. XII, 1919.

[2] We have also examined some soils from Srinagar-Kashmir, (analysis not given), but Srinagar being situated on a plateau of high altitude, and the locality from which these were taken situated at the foot of a small hill called Mahadev, does not show the characteristics of hill soils. The analyses of these soils therefore, is not comparable with those of the Kangra soils. We hope to take up the study of the hill soils separately.

2. The addition of lime to such soils has not resulted in any increase in the crop yield.

Such soils do not at present show any indication of lime deficiency but it is possible that the quantity of lime present therein may be exhausted much sooner than from soils in regions of high lime content and hence carefully controlled observations are necessary as time goes on.

Investigations are in progress at the present time in the Lyallpur Laboratories to study the relationship between the mineral constituents of the soil and the nutritive value of crops raised therefrom. This work when completed should give some insight into the connection between the lime content of soils and the yield of various crops. As has been found, a great deal of lime is removed by crops from the soil, more especially by fodder crops such as, Lucerne and Alfalfa, and the question of confining these crops to particular areas or of liming soils on which these are grown suggests itself for careful consideration. At present the soil with the lowest lime content may still be sufficiently rich in this mineral to produce satisfactory crops, but future depletions of the soil with consequent deterioration of crops from the point of view of calcium content and general mineral balance deserves careful watch and attention.

It might appear from such information as is at present available that there is some definite relative proportion of the mineral elements necessary for the different soils of the Province, under which conditions the soil functions as a "Normal Soil" for the locality, but if this balance of plant food in the soil is disturbed by removal or addition of food ingredients then it may behave abnormally.

The data at present available, however, render it necessary to present such an opinion with some reserve and a much closer and more detailed study of these soils is essential in order that one may be in a position to diagnose their present condition and take due steps for the upkeep of their fertility. The picture which we have endeavourd to draw shows that the question of the lime content is but one of the many future lines of investigation.

4. *Lime and Magnesia.*

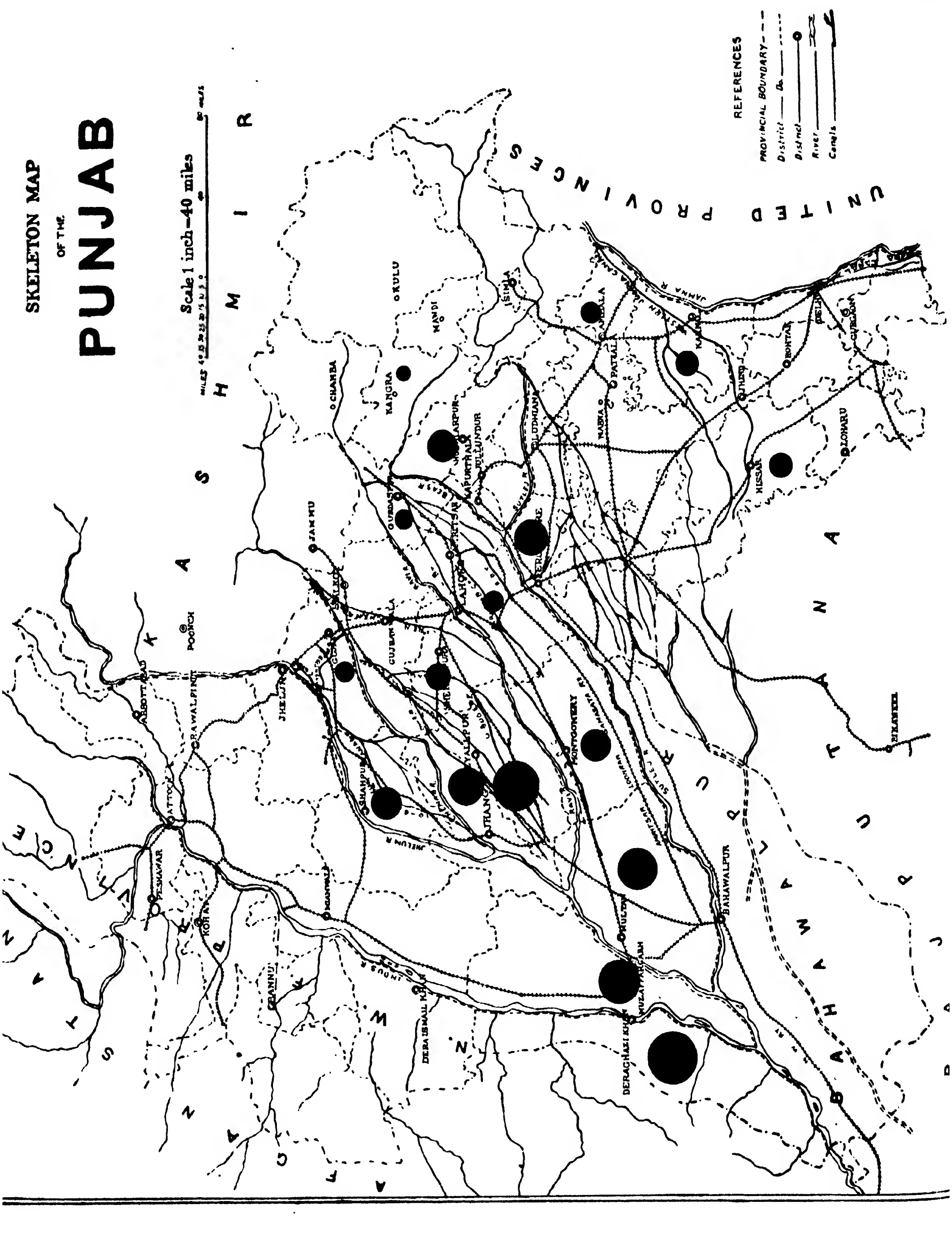
The two metals calcium and magnesium are very closely associated in nature and in conjunction with carbon dioxide they constitute the limestone beds of the world. Magnesium is an indispensable plant food and so is lime. Both are found in the seed of the plant. magnesium even more so than calcium.

Kearney and Cameron in America have shown that salts of magnesium possess, even in solution of great dilution, a toxic affect upon the roots of the plants, which is considerably diminished if calcium salts be also present at the same time. Loew has, at the same time, indicated that a comparative excess of magnesium over calcium in the case of certain soils results in sterility.[1] Thus we see that

[1] Hall, A. D. The Soil. John Murray, Albemere Street London, W., 1921.

DIAGRAM IX.

Showing, lime: Magnesia ratio in soils from different districts of the Punjab.



great importance attaches in soil chemistry to the lime : magnesium ratio. Gila and Ageton (*Jour. Indust. and Eng. Chem.* 1913), have found that certain fertile soils have a ratio as big as 500 : 1. However, in the case of most of the soils the ratio varies between 1 : 1 and 7 : 1.

The quantity of magnesia in the Punjab soils does not vary so greatly as does that of lime. Magnesia is found to an extent of 0·5 per cent. to 3·0 per cent. in the soils we have examined, but most of the figures fall between 1 and 2 per cent. The average figures for the lime-magnesia ratio of the soils tabulated in Tables I and V are depicted in diagram 9, from which it will be clear that the lime-magnesia ratio, with the exception noted above, follows with considerable uniformity the same order as does the lime. For most of the Punjab soils we have examined the ratio varies between 1 : 1 and 6 : 1. We are not yet in possession of sufficient data to enable us to see if any correlation exists between the lime-magnesia ratio and the productiveness of the soils.

5. *Potash.*

Generally speaking the Punjab soils are not deficient in potash. The average quantities found for 150 samples examined is 0·72 per cent., while the sub-soils show an average figure of 0·66 per cent. These figures as well as those for the potash : clay ratio are given in Table VI. From 116 samples for which these ratios are given, a very large number have values of more than 0·35, while only 23 have a ratio of less than 0·35. Thus for most of the Punjab soils potash constitutes $\frac{1}{20}$th to $\frac{1}{10}$th of the clay fraction. The 23 soils referred to above should improve with a dressing of potassic fertiliser, as most of these are heavy soils.

6. *Phosphoric acid.*

The largest amount of phosphoric acid found by Hall and Russell in their survey of the soils of Kent and Sussex was from 0·2 per cent. to 0·25 per cent.[1] Bennet[2] in his study of the soils of the southern states of America found that the maximum content of phosphoric acid in any soils was 0·67 per cent. Most of his soils, however, contain less than 0·05 per cent. Robinson[3] gives 0·09 as the average P_2O_5 content of 35 American surface soils. The highest phosphoric acid content that we have come across in any of the Punjab soils was met with in one sample from Dehra Ghazi Khan, *viz.*, No. 233, with 1·36 per cent. and in another from Shahpur No. 187 which contained 1·60 per cent, these figures, however, are very abnormal. Otherwise most of the Punjab soils have a P_2O_5 content lying between 0·1 to 0·3 per cent., the average of 154 samples working out to 0·18 per cent. The average P_2O_5 content for the subsoils works out at 0·16 per cent. (Table VII.)

[1] **Hall, A. D.; and Russell, E. J. Soil Surveys and Soil analysis.** ***Jour. of Agri. Sci.***, Vol. IV, pp. **182-224.**

[2] **Bennet, H. H. The Soils and Agriculture of the Southern States. 1921.**

[3] **Robinson.** *Loc. cit.*

7. *Iron and Aluminium.*

Iron and Aluminium have been estimated separately in 71 surface soils and 50 subsoil samples (Table VIII). Most of the surface soils have an iron content lying between 3 per cent. and 5 per cent., while the average for 71 samples is 4·11 per cent. although figures as low as 1·28 per cent. and as high as 5·99 per cent. are also known. Similarly for aluminium most of the figures lie between 4 per cent. and 7 per cent. the average being 5·37 per cent. with a lowest figure of 2·18 per cent. and a highest of 10·19 per cent. The average of the iron aluminium ratio is 0·71, while the lowest ratio met with was found in the Shahpur soils, *viz.*, 0·59 and the highest in those from Amballa, 1·29. The surface soils from Hissar, Karnal, Ferozepur, Sheikhupura and Multan have an iron aluminium ratio about equal to the average figure found. There is a remarkable feature about this ratio. As one moves from the south northwards along the sub-mountain tract, a steady decrease in this ratio is found as shown by the following figures :—

Amballa	1·29
Gurdaspur	·98
Rawalpindi	·75
Attock	·67

and until a considerably larger number of figures is available for these tracts, it is very difficult to say whether any particular significance attaches to them. In the subsoils we find that the figures show a greater uniformity and also are higher than in the surface soils. Most of the samples have an iron content between 3 per cent. and 6 per cent. and an aluminium content between 4 per cent. and 9 per cent., the highest figures being of the same order as for the surface soils.

8. *Aluminium-Clay ratio.*

Table VI gives the figures for the aluminium-clay ratio. Out of 103 samples presented, the majority, *viz.*, 67 have a ratio lying between 0·3 and 0·5 ; 23 have figures less than 0·3, and 13 more than 0·5. Thus for the majority of these soils, alumina constitute one-third to one-half of the clay fraction. The soils from the south of England have figures for alumina which are, generally speaking, one-third of the clay fraction[1].

9 *Silica : Alumina : Bases.*

Ganssen makes the generalisation that the ratio $SiO_2 : Al_2O_3$: Bases (CaO, MgO, K_2O, Na_2O) is 3 : 1 : 1, in fertile soils and 3 : 1 : less than 1 in infertile soils. In the English fertile soils the ratio Al_2O_3 : bases is 1 : 1, while in infertile soils it is 1 : less than 1.[2]

We do not possess figures for the amount of alumina and the above bases in the clay fractions of the Punjab soils comparable with the above. However, these

[1] Russell, H. H. Soil condition and plant growth.
[2] Russell, E. J. *Loc. cit.*

ratios for the soil as a whole are given in Table VIII, and, taking the mean averages for different districts we get the following figures :—

——	Residue Al_2O_3	Bases Al_2O_3	Surface Soil	Subsoil
Amballa	30·24	·9	30·24 : 1 : ·9	....
Gurdaspur	21·80	·7	23·38 : 1 : ·7	20·20 : 1 : ·53
Rawalpindi	14·01	2·7	11·77 : 1 : 2·3	16·57 : 1 : 3·19
Hissar	15·64	·7	15·70 : 1 : ·56	12·76 : 1 : ·71
Karnal	15·85	·53	17·57 : 1 : ·58	13·55 : 1 : ·5
Ferozepur	13·06	1·4	13·61 : 1 : 1·4	12·49 : 1 : 1·5
Montgomery	16·41	1·4	16·87 : 1 : 1·45	15·49 : 1 : 1·4
Lyallpur	17·45	1·0	18·76 : 1 : ·95	17·14 : 1 : 1·1
Shahpur	11·63	1·05	11·30 : 1 : ·94	11·55 : 1 : 1·17

It will be seen from the above that this ratio, alumina to bases is 1, or more than 1 for the districts included in the north-west dry area. Ferozepur, which has most of its tract lying on the south-east boundary of this area and has many climatic and physical features in common with this, has got as high a ratio as Montgomery. This means that more inorganic plant food is available in soils from the dry area of the Punjab than in soils from the southern and sub-montane[1] tracts of the Province. Perhaps more heavy rainfall and more intensive cultivation followed in these latter districts is responsible for the more rapid depletion of plant food.

Looking at Table IX we find there is invariably more soluble matter present in the subsoil than in the surface soils. Generally speaking, the bases, calcium, magnesium, sodium and potassium are also present in greater quantity in the sub soils.

8. Some Important crops of the Province.

1. *Wheat.*

Wheat is grown throughout the Province and on all types of land. It possesses considerable power of adaptation and is less localised than, for example, potatoes, rice and fruits. It generally does best on medium loams. Typical examples of wheat soils are given in Table X. These include almost all types of loam, sandy, medium silt and clay soils.

[1] The figures for Rawalpindi are abnormal owing to high amount of calcium present.

2. *Cotton.*

Cotton does quite well on all soils suitable for wheat except that it (more particularly American cotton) requires a comparatively richer soil with a greater and more certain supply of water. It is less hardy as compared with wheat. The analyses of typical cotton soils of the Province are represented in Table XI.

3. *Sugarcane.*

The analyses of those soils of the Province which have proved suitable for sugarcane are given in Table XII. It will be seen that sugarcane requires a somewhat heavier soil than wheat or cotton. It has also been observed that a moderate percentage of gravel in a soil does not detract from its value for cane production. Cane is the only crop which has shown any indication of a "possibly" successful yield in the abnormal *bara* soils of the Montgomery district.

Soils 16 and 19 in the same Table are somewhat too light for the best production of sugarcane, but as they happen to lie in the sub-montaneous tracts they receive a fairly heavy rainfall which counteracts to some degree the lightness of the soils and renders them moderately suitable for cane. This explanation, however, does not hold good for soil No. 103 from Hissar. This soil, though a sandy loam, has the whole of its sand present as fine sand, which confers on it properties similar to those of silt soils.

4. *Rice.*

Some typical rice soils of the Province are shown in Table XIII. It will be seen that rice grows successfully only in heavy soils.

From the table it will be clear that all the samples analysed contain either a fairly high percentage of clay or they are rich in silt and fine silt ingredients which tend to make a soil heavy. All these soils are very rich in iron and aluminium as compared with the wheat, the cotton, and the sugarcane soils.

The soils suitable for different crops are represented in Diagrams 3—6, according to their mechanical analysis.

9. Subsoils.

The analyses of about 50 samples of subsoils are presented in this paper. The surface soil includes the soil layer sampled down to a depth of one foot and the subsoil represents the layers lying below this as far as the third foot. The results of analyses of these subsoils, together with those of the corresponding surface soils, are given in Table I (*a*). The mechanical composition of most of these subsoils and surface soils is represented graphically in Diagram 7. It is clear from the diagram, that with two or three exceptions, the subsoil—although it has a distinct tendency to be heavier than the surface soil—is not widely separated on the scale from the surface soil; as a matter of fact in the large majority of cases, the

soil and the corresponding subsoil fall in one and the same compartment on the graph ; thus showing that they belong to the same soil type.[1]

From a consideration of the relative figures for the more important chemical constituents (Table I*a*), we find that there is no appreciable difference in the amount of potash and phosphates present in the surface soil and subsoil below. Calcium, on the other hand, is in some cases present in greater amount in the surface soils and in some cases in the subsoils. The differences in the amount of nitrogen and organic matter, although not very wide, point to some striking conclusions. As a general rule, in the majority of cases, the amount of nitrogen is greater in the surface soil than in the subsoil, while, on the other hand, the organic matter is less in the surface soil. The greater amount of nitrogen in the surface soils may be due to the greater acitivity of the nitrogen fixing organisms in the upper layers. However, more extensive examination of the soils is necessary before any generalisation is possible.

Such small differences referred to above, however, do not cause any serious modification in the character of the subsoil. It may be safely asserted that, as a general rule, throughout the Punjab the subsoil does not differ very materially from the surface soil either in its chemical or mechanical composition, and owing to this uniformity the properties of the surface soil instead of being in any way modified are merely intensified.

10. The Barren lands of the Province.

(*a*) ALKALI SOILS.

Although much of the barren land of the Punjab owes its non-fertility to its excessively sandy nature, as in various parts of the Thal, or in some of the baram tracts of the Central Punjab, yet taken on the whole their sterility is caused by the presence of excessive quantities of alkali salts.

Most of these *kallar* lands contain only white alkali such as chlorides and sulphates of sodium, but the occurrence of black alkali is not uncommon. No records are available from which we may accurately compute the exact amount of *kallar* land in the Province, but rough estimates show that smething like 4,000 square miles of *kallar* exist throughout the Punjab.[2] With the increasing development of the Punjab canal system, the problems connected with *kallar* and waterlogging are yearly increasing and becoming more accute. Generally speaking, these alkali salts are present in harmful degree only in the first few inches of the surface soils, but sometimes the subsoil layers are also found to be impregnated with salt, in which case problems of reclamation become increasingly difficult. The analyses of the water extracts of the alkali soils from various parts of the Province

[1] Wilsdon, B. H. *Loc. cit.*
[2] Mehta, M. L. Occurrence of Saline lands in the Punjab. *Proceedings of the 4th annual gathering of the Old Boys Association of the Punjab Agricultural College, Lyallpur,* India, 1924.

are given in Table XIV and when a total water soluble figure above 0·8 per cent. is found it may be assumed that we are dealing with a *kallar* soil.

The chief sources of origin of alkalis in the Punjab are attributable to :—

1. Movement of subsoil water currents from high water levels to lower ones and the accumulation of salt on account of the evaporation of water from the land to which it has drained.
2. Contamination from salt mines.
3. Seepage from canals, the result of which is waterlogging and as a result of free evaporation an accumulation of salt on the surface.
4. The constructions of canals. Sometimes the surface drainage of the country is disturbed owing to this cause, the result being an accumulation of salt in the soil.
5. The formation of vast sheets of stagnant water or huge lakes.
6. Bad aeration and drainage.

The last, according to Howard, results in the production of hydrogen sulphide and metallic sulphides through the agency of anerobic bacteria. These products, upon cultivation, *i.e.*, improvement in aeration and drainage, are oxidised to harmful alkali salts which rise to the surface.

The only methods which have so far been tried with any degree of success in order to reclaim alkali lands are, firstly the scraping of salts from the surface and secondly the construction of mole drains and subsequent flooding to wash the salt to lower subsoil strata. At the present time the effect of calcium in destroying the "Soda Complex," *i.e.*, sodium silicates which renders the land hard and impermeable to water, is being studied, but the work is still in an experimental stage.

(*b*) *Bara*.

Bara soil is an alkali soil which presents certain very peculiar and distinguishing features. It is extremely arid, dense in texture, and most intractable. It is highly charged with salts and usually cracks into hexagonal shaped clods which on drying form a thin and peculiar crust which can be peeled off. Water, when applied to the surface of *Bara* soil, hardly percolates at all, but merely evaporates, leaving a surface of extraordinary hardness which produces a metallic sound when a horse rides over it and exhibits very clearly the phenomena of mirage when seen from a distance. The surface layer (*papri*) usually contains as much as 80 per cent. clay (Table below), and is very impervious to water.

Mechanical analysis of Papri

Fine gravel	*nil.*
Coarse sand	*nil.*
Fine sand	*nil.*
Silt	3·28 per cent.
Fine silt	13·00 per cent.
Clay	78·40 per cent.

This material, although containing such a high percentage of clay is not at all sticky when wet, and if kept under water for an hour or so, does not pass into suspension; on the other hand, it is possible to separate this clay into layers of several fine leaves. If this *papri* is treated with water and kept for a couple of days it develops a very offensive smell. but not so in the presence of mercury chloride. Shells of various sizes and description have been found in the *bara* soils from which fact it may be concluded that the soil was most probably deposited under water, the water gradually evaporating and leaving behind deposits of soluble salt. An analysis of typical *bara* and normal lands in the Montgomery district is given in Tables XV and XVI.

(c) BARI.

This is a lighter type of *bara*.

It has been estimated that in the Montgomery Colony alone there exists something like 3 lakhs of acres of *bara* and *bari* types of land, and on enquiry it was found that another 163,186 acres of similar land are found in the adjoining districts.

The problem of the reclamation of *bara* has presented many difficulties. An experimental station near Harrappa Road Railway station (N. W. R.) was started some 9 years ago for the study and investigation of the most economical methods of reclaiming these lands. An economic method of reclaiming *bara* land has not yet been found, but work is still progressing and so far the application of gypsum followed by flooding and the planting of trees have given the best results.[1] There is no doubt that the land can be reclaimed provided sufficient time and money are forthcoming.

It has been noticed that *bara* land shows a tendency to pass into ordinary *kallar* both with and without any treatment with water. One square of land on the experimental farm was under flooding experiments in 1925, when it was kept under 6 inches of water for about 3 months. In 1926 only a part of this land was under water, the rest was either sown with *chari* and *moth* or kept fallow. All that portion, not actually under water, developed *kallar* on its surface, scrapings from which on analysis gave the following figures :—

	per cent.
Total saline matter	8·15
Carbonates	0·02
Bicarbonates	0·03
Chlorides	2·26
Sulphates	5·27

This shows that the land has developed a very bad type of white alkali.

[1] Nasir, S. M. Some observations on the Barren Soils of Lower Bari Doab Colony in the Punjab. *Agri. Research Institute, Pusa, Bull.* 145, 1923.

11. Some Virgin lands.

In the year 1920, a preliminary reconnaissance of the crown lands covered by the Sutlej valley project (Nili Bar) was undertaken, mainly with the object of making a preliminary study for a more detailed and scientific survey of these lands later on, schemes for which were under the consideration of Government.

During the course of this inspection, a few samples of soils were taken from some of the typical tracts of the Bar and their analyses are given in Table XVII. It is not proposed to describe in any detail the effect of development on them or to discuss the best method of handling them when first colonised, but the analyses are presented in the hope that they will be useful for future reference. Soil No. 1 was taken from an uncultivated field of land commanded by a well (Faqirwala) near the town of Kabullah. The lands near by bear fairly good crops under well irrigation.

Soil No. 2 was taken from a tract situated on the road between Kabullah and Tibi Lal Beg and was covered by a forest of Karil (*Capperis-aphylia*), Van (*Salva-Dora Olsides*) and Jand (*Presopis Spicigera*) trees. It grows a very good crop of grass and was being used for grazing cattle. The land is rather hard on the surface, but the subsoil layers are decidedly sandy.

Soil No. III is from a similar tract on the same road.

Soil No. IV. This was taken from lands situated in the village Sadullahpur which lies between Jamlera and Kabullah. The soil is very good and is expected to yield good crops when brought under cultivation.

Soil No. 5. This sample was taken from a plot at Jamlera. It is at present commanded only by flood water from the river Sutlej. The land was covered by a very thick forest of Jand (*Prosopis Spicigera*) trees and provided the best type of soil found.

Soil No. 6. This is of the same type as No. 5 although not considered to be as good. It was taken from land commanded by the Matewala well, but was neither irrigated nor cultivated.

Soil No. 7. This was taken from a place named Bisakhiwala from the portion of the Nili Bar situated in the Multan district.

Table No. XVI shows some analyses of good soils of the Montgomery colony before they were first broken up for cultivation.

From the foregoing it is clear that a considerable diversity of soil types exists in the Province. Taking into consideration the variety of climatic conditions prevailing in the different parts of the Punjab, it seems obvious that a more detailed study of the soils of the Province is a necessity in order to elaborate successfully a more exact system of crop and animal husbandry. For this purpose a regular soil survey is necessary. A soil survey is essentially an inventory of the soils of the State, and corresponds to the work of the geological survey which investigates the mineral resources, such as coal, iron, oil, etc., in order to discover new deposits and determine the extent of those already present. It is essentially

important that Government should undertake soil investigations of this kind so that the soil, the primary source of wealth, may be utilised to yield to its maximum capacity, and conserved in good condition to subserve the needs of future generations. As agriculture is the chief and the only permanent basis of the wealth of the Province, the necessity of comprehensive studies in this field is obvious.

The work of the Bureau of soils of the United States Department of Agriculture may be quoted as an example of activities in this direction.[1] More than 1,220,000 sq. miles, or over 40 per cent. of the total area of the United States, has now been surveyed, and the surveys are progressing at the rate of about 30,000 sq. miles per year. The usefulness of the undertaking has been very much increased by supplementing the general survey in various ways, notably with more detailed studies of the various soil types, their fertility needs and adaptability to diffierent crops.

As a result of these exhaustive surveys, many experimental stations have been established each of which is engaged on specific soil problems specially related to the area in which the station is situated.

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[1] Reports of the third annual meeting of the American Association of Soil Survey Workers. Vols I—VI, 1922-26.

12. Appendix A.

METHOD FOR THE MECHANICAL ANALYSIS OF SOILS.

At Lyallpur a centrifugal method of separating clay has been introduced and has been found to give satisfactory results with considerable economy of time.

The method followed is the same as that given by Auld and Ker[1] with the modification that samples are prepared in a specially constructed shaking machine and that clay is separated by spinning out muddy liquids in a centrifugal machine specially made for this purpose.

Appendix B.

THE MECHANICAL ANALYSIS OF SOILS.

1. *Water extract.*

200 grams of the air dried fine earth are taken up in Winchester bottle in 2,000 c.c. of distilled water. The bottle is shaken after every 15 minutes and allowed to stand overnight. The muddy liquid is then filtered through a Berkefeld filter pump.

50 to 100 c.c. of the water extract is evaporated to dryness in a platinum dish and weighed; the difference in weight after allowing for the loss of carbon dioxide and water gives the amount of total solids.

Chlorides, carbonates and bicarbonates are estimated by the usual volumetric methods, while sulphates are estimated gravemetrically.

2. *Citric acid extract.*

200 grams of air dried soil are placed in a Winchester bottle with two litres of 1 per cent. citric acid. The bottle is occasionally shaken and the soil allowed to remain in contact with acid for a week, after which the extract is decanted and analysed.

3. *Hydrochloric acid extract.*

20 grams of air dried fine soil are treated with 60 c.c. of strong hydrochloric acid in a conical flask. The flask is put on the sand bath and the contents heated for 8 hours at such a temperature as to cause occasional ebullition. After this the extract is filtered and made up to 500 c.c.s.; aliquots of the filtered extract are then taken for the estimations.

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[1]Auld and Ker. Practical Agricultural Chemistry.

4. *Organic nitrogen.*

The Gunning method, involving the use of one gram of $CuSO_4\ 5H_2O$ with subsequent addition of 10 grams of K_2SO_4, is in use at Lyallpur. The quantity of soil used is 20 grams.

5. *Total nitrogen.*

The nitrates are reduced by digesting the soil with 6 per cent. salicyl sulphuric acid.

TABLE I.

Analyses of the Punjab Soils.

LOCALITY	KANGRA							AMBALLA	
						BAIJ NATH			
DESCRIPTION	Dharamsala		Holta	Nur Nassam	Nassam	Lower garden	Upper garden		
Number	1	2	3	4	5	6	7	8	9
Mechanical.									
Fine gravel	23·2	9·27	0·91	0·76	0·88	0·39	0·60	*nil*	*nil*
Coarse sand	40·0	26·18	1·12	2·81	0·69	2·47	33·30	0·89	0·34
Fine sand	16·18	17·93	7·06	6·87	8·17	8·17	18·87	71·79	13·49
Silt	7·30	13·18	23·60	20·60	24·90	32·41	12·51	13·07	30·68
Fine silt	6·88	15·95	21·74	20·46	23·40	25·20	18·40	7·36	32·80
Clay	5·8	12·10	33·60	35·05	36·21	19·00	11·72	4·80	19·60
Chemical. (*H Cl extract*)									
Potash as K_2O	0·714	0·687	0·728	0·683	0·713	0·423	0·414	0·411	0·974
Phosphoric acid as P_2O_5	0·340	0·790	0·390	0·470	0·340	0·296	0·224	0·160	0·213
Lime as CaO	0·058	0·035	0·092	0·081	0·127	0·260	0·090	1·190	0·850
Magnesia as MgO	0·290	0·360	0·660	0·280	0·780	0·304	0·110	0·851	1·359
Iron and Aluminium (Fe_2O_3) Al_2O_3	10·890	10·750	21·80	22·22	19·55	11·61	14·41	6·910	13·552
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·050	0·150	0·076	0·050	0·110	0·110	0·100	0·020	0·054

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	AMBALLA					HOSHIARPUR		GURDASPUR	
DESCRIPTION									
Number	10	11	12	13	14	15	16	17	18
Mechanical.									
Fine gravel	*nil*	*nil*	*nil*	0·048	0·044	0·68	0·03	*nil*	*nil*
Coarse sand	2·96	19·135	14·10	25·92	9·18	21·02	36·60	14·88	6·08
Fine sand	50·82	43·27	34·33	47·84	51·12	41·46	38·54	31·84	15·84
Silt	24·63	15·28	17·07	10·53	17·72	14·40	10·88	23·47	28·05
Fine silt	11·36	10·96	19·68	8·96	11·76	10·88	6·4	23·25	40·39
Clay	6·72	6·08	9·92	7·44	10·56	8·32	7·04	4·09	4·62
Chemical.									
Potash as K_2O	0·22	0·27	0·29	0·46	0·48	0·599	0·418	0·688	0·638
Phosphoric acid as P_2O_5	0·139	0·107	0·242	0·184	0·145	0·458	0·133	0·163	0·178
Lime as CaO	0·93	1·04	0·72	1·05	1·09	2·510	·625	0·485	0·520
Magnesia as MgO	1·15	1·05	1·19	0·91	1·06	1·100	·849	2·250	1·950
Iron and Aluminium (Fe_2O_3) Al_2O_3	3·21+ 2·53	3·29+ 2·44	3·68+ 3·97	2·34+ 3·57	2·95+ 3·73	6·712	5·842	11·922	9·807
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·061	0·039	0·053	0·039	0·041	0·052	0·055	0·075	0·058

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	GURDASPUR								
DESCRIPTION									
Number	19	20	21	22	23	24	25	26	27
Mechanical.									
Fine gravel	*nil*	0·71	0·14	0·24	0·16	0·11	0·24	0·16	0·29
Coarse sand	35·99	7·46	23·09	38·29	40·93	28·07	32·94	36·56	40·84
Fine sand	30·22	31·64	33·11	19·92	21·52	28·21	24·30	24·47	19·75
Silt	11·52	23·40	19·85	17·24	16·85	20·47	20·08	17·98	16·36
Fine silt	10·24	20·48	12·16	13·60	12·24	13·36	13·04	12·56	14·96
Clay	9·28	11·20	9·12	6·40	5·92	6·40	6·40	6·32	7·36
Chemical.									
Potash as K_2O	0·744	0·831	0·688	0·366	0·343	0·381	0·448	0·422	0·443
Phosphoric acid as P_2O_5	0·113	0·105	0·055	0·710	0·650	0·560	0·640	0·620	0·820
Lime as CaO	0·370	0·835	0·390	0·350	0·300	0·510	0·300	0·480	0·430
Magnesia as MgO	1·400	1·630	1·050	0·460	0·980	1·170	0·880	1·170	1·230
Iron and Aluminium (Fe_2O_3) Al_2O_3	8·707	10·695	7·325	7·820	7·400	7·490	7·620	7·050	7·230
Potash (available)	..	..	..	0·015	0·014	0·013	0·015	0·014	0·017
Phosphoric (available)	..	..	..	0·023	0·032	0·025	0·026	0·020	0·025
NITROGEN (% on air dried soil)	0·033	0·047	0·032	0·048	0·045	0·046	0·049	0·046	0·048

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	GURDASPUR								
DESCRIPTION									
Number	28	29	30	31	32	33	34	35	36
Mechanical.									
Fine gravel	1·14	0·25	0·41	0·48	0·23	0·11	..	..	..
Coarse sand	25·96	23·00	23·87	8·13	14·30	23·70	..	..	..
Fine sand	28·10	22·91	31·30	19·02	25·84	27·23	..	..	..
Silt	16·10	20·01	17·92	27·45	26·82	25·44	..	..	..
Fine silt	12·71	17·93	12·99	26·02	18·20	12·94	..	..	..
Clay	10·23	15·60	12·48	12·96	9·28	7·36	..	..	..
Chemical.									
Potash as K_2O	0·351	0·304	0·292	0·314	0·336	0·317	0·910	1·250	1·030
Phosphoric acid as P_2O_5	0·449	0·435	0·486	0·409	0·438	0·330	0·120	0·160	0·140
Lime as CaO	0·900	0·280	0·270	0·290	0·294	0·271	..	..	..
Magnesia as MgO	1·030	0·970	0·820	0·620	1·040	0·790	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	8·080	9·010	6·870	10·840	8·470	8·070	..	..	..
Potash (available)	0·050	0·032	0·027	0·023	0·023	0·022	0·012	0·016	0·017
Phosphoric (available)	0·147	0·082	0·112	0·035	0·066	0·038	0·009	0·033	0·013
NITROGEN (% on air dried soil)	0·063	0·058	0·052	0·078	0·075	0·052	0·059	0·078	0·048

TABLE I—*contd.*

Analysis of the Punjab Soils—contd.

LOCALITY	GURDASPUR								
DESCRIPTION									
Number	37	38	39	40	41	42	43	44	45
Mechanical.									
Fine gravel	..	..	..	..	..	..	..	..	..
Coarse sand	..	..	..	..	..	..	..	..	..
Fine sand	..	..	..	..	..	..	..	..	..
Silt	..	..	..	..	..	..	..	..	..
Fine silt	..	..	..	..	..	..	..	..	..
Clay	..	..	..	..	..	..	..	..	..
Chemical.									
Potash as K_2O	0·940	1·700	1·380	0·880	0·720	0·870	0·910	0·990	1·220
Phosphoric acid as P_2O_5	0·070	0·180	0·100	0·050	0·060	0·060	0·065	0·180	0·070
Lime as CaO	..	..	..	..	..	..	..	..	..
Magnesia as MgO	..	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	..	..	..	..	..	..	..
Potash (available)	0·014	0·015	0·022	0·010	0·061	0·050	0·025	0·011	0·014
Phosphoric (available)	0·011	0·013	0·011	0·011	0·008	0·026	0·025	0·019	0·011
NITROGEN (% on air dried soil)	0·057	0·085	0·070	0·050	0·056	0·055	0·063	0·050	0·062

TABLE I—*contd.*

Analysis of the Punjab Soils—contd.

LOCALITY	GURDASPUR							
DESCRIPTION			1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.
Number	46	47	48	49	50	51	52	53
Mechanical.								
Fine gravel	..	*Nil*	*nil*	·40	*nil*	*nil*	*nil*	*nil*
Coarse sand	..	30·01	23·41	23·83	12·44	*nil*	11·04	15·33
Fine sand	..	32·27	21·39	18·94	51·59	36·79	31·57	29·19
Silt	..	16·70	18·90	17·60	23·61	20·68	35·14	31·82
Fine silt	..	12·72	19·57	20·65	8·92	14·32	13·34	14·99
Clay	..	6·24	14·80	21·36	6·84	19·04	7·28	11·70
Chemical.								
Potash as K_2O	1·260	..	0·52	0·57	0·43	0·53	0·48	0·44
Phosphoric acid as P_2O_5	0·050	..	0·10	0·11	0·08	0·06	0·16	0·14
Lime as CaO	..	..	0·56	0·28	0·84	0·85	0·41	0·39
Magnesia as MgO	..	..	1·26	1·36	1·20	1·53	1·77	0·83
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	4·24 4·68	4·60 5·33	3·16 3·47	3·52 4·35	3·08 3·56	3·38 3·77
Potash (available)	0·012	..	..	..	..	..	..	..
Phosphoric (available)	0·016	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·053	..	0·059	0·066	0·075	0·043	0·033	·066

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	RAWALPINDI						ATTOCK		
							VILLAGE SADKAL		
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	3rd ft.
Number	54	55	56	57	58	59	60	61	62
Mechanical.									
Fine gravel	0·53	0·22	0·14	0·02	0·21	0·06	0·63	..	0·42
Coarse sand	2·37	1·26	1·02	·70	35·70	31·58	1·50	1·60	1·40
Fine sand	26·86	25·58	19·38	19·82	29·70	28·86	28·52	26·38	13·58
Silt	32·15	34·50	25·96	27·20	16·18	16·41	28·13	27·41	31·56
Fine silt	17·92	17·36	24·80	24·24	6·16	9·60	18·80	22·96	26·40
Clay	13·92	14·08	22·08	22·24	8·64	6·72	21·56	23·00	27·25
Chemical.									
Potash as K_2O	0·700	0·586	0·496	0·514	0·302	0·469	0·765	0·882	0·727
Phosphoric acid as P_2O_5	0·198	0·175	0·214	0·208	0·160	0·172	0·170	0·190	0·176
Lime as CaO	11·44	10·13	11·20	11·39	9·07	9·55	1·95	1·99	1·97
Magnesia as MgO	1·75	1·76	2·17	2·39	1·19	1·28	1·27	1·21	0·97
Iron and Aluminium (Fe_2O_3) Al_2O_3	5·09 5·95	4·93 5·38	3·66 5·91	3·40 3·48	4·52 5·86	4·48 3·92	4·32 7·13	4·50 8·86	4·31 6·11
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·067	0·086	0·041	0·048	0·059	0·046	0·053	0·050	0·045

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	ATTOCK								
	VILLAGE AJJUWALA			VILLAGE KHARALA KHURD			VILLAGE JHANG (IRRI).		
DESCRIPTION	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Number	63	64	65	66	67	68	69	70	71
Mechanical.									
Fine gravel	0·88	0·98	0·62	0·93	0·93	1·23	0·73	0·81	1·18
Coarse sand	5·40	4·58	3·20	4·20	4·20	6·01	1·97	1·61	1·40
Fine sand	25·88	23·02	8·88	31·70	32·68	27·38	18·40	18·31	18·01
Silt	12·62	8·84	9·44	23·94	25·66	22·55	30·27	31·96	27·18
Fine silt	27·44	29·60	40·00	22·00	21·44	22·80	30·00	29·76	32·40
Clay	27·28	32·40	39·52	21·62	20·98	19·35	20·58	21·12	20·56
Chemical.									
Potash as K_2O	0·552	0·46	0·780	0·424	0·407	0·395	0·202	0·616	0·597
Phosphoric acid as P_2O_5	0·100	0·149	0·105	0·165	0·090	0·101	0·157	0·104	0·095
Lime as CaO	12·81	12·88	12·88	7·71	8·37	7·90	8·89	2·35	5·95
Magnesia as MgO	1·57	1·68	1·59	2·29	2·30	2·46	1·99	2·23	1·92
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·21 6·31	4·30 5·84	4·22 7·89	4·93 6·78	4·32 5·68	5·60 6·64	5·99 7·73	6·00 9·37	5·48 7·67
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·071	0·055	0·054	0·037	0·037	0·043	0·093	0·054	0·043

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	ATTOCK								
DESCRIPTION	VILLAGE JHANG BARANI			VILLAGE NEKA (IRRI.)			VILLAGE NEKA BARANI		
	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Number	72	73	74	75	76	77	78	79	80
Mechanical.									
Fine gravel	1·48	1·05	1·76	2·26	1·42	1·46	1·52	1·56	0·88
Coarse sand	3·20	2·00	1·54	7·40	4·50	3·18	5·44	5·50	5·58
Fine sand	39·29	22·09	17·32	20·42	25·63	21·08	33·54	31·06	26·56
Silt	22·39	30·48	28·78	24·08	23·08	26·64	26·00	24·24	27·51
Fine silt	17·76	27·36	30·40	22·68	21·86	24·40	16·32	20·00	17·20
Clay	14·28	17·63	22·36	21·44	25·80	25·20	16·80	19·20	17·62
Chemical.									
Potash as K_2O	0·524	0·543	0·638	0·677	0·716	0·519	0·632	0·491	0·485
Phosphoric acid as P_2O_5	0·104	0·091	0·129	0·365	0·280	0·271	0·260	0·162	0·192
Lime as CaO	5·89	4·51	3·95	9·14	8·85	8·74	8·20	10·92	10·92
Magnesia as MgO	1·65	1·45	1·80	2·20	0·95	1·02	1·08	1·49	1·00
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·72 6·01	5·20 7·83	6·08 7·67	4·08 5·67	3·36 8·96	3·41 7·69	3·58 9·29	3·20 9·42	3·69 7·06
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·047	0·049	0·077	0·090	0·062	0·062	0·069	0·067	0·065

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	ATTOCK								
	VILLAGE KUTBAL			VILLAGE DOIAN			VILLAGE KHUNDA		
DESCRIPTION	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Number	81	82	83	84	85	86	87	88	89
Mechanical.									
Fine gravel	2·76	0·96	2·92	5·04	5·74	1·34	0·62	0·59	0·76
Coarse sand	5·97	5·86	7·57	4·50	8·44	4·78	24·95	21·64	21·00
Fine sand	17·48	24·18	20·64	27·17	22·58	22·60	20·96	22·38	23·08
Silt	28·48	24·40	25·70	24·64	23·84	28·30	12·38	17·19	15·97
Fine silt	24·00	26·00	25·44	19·60	22·40	22·40	26·40	20·50	20·24
Clay	19·20	19·04	16·96	20·28	17·86	19·20	14·50	16·00	15·00
Chemical.									
Potash as K_2O	0·517	0·798	0·650	0·872	0·836	1·062	0·764	0·810	0·750
Phosphoric acid as P_2O_5	0·200	0·095	0·116	0·124	0·078	0·044	0·036	0·040	0·038
Lime as CaO	12·18	11·31	12·04	13·20	16·60	9·83	5·10	6·16	16·05
Magnesia as MgO	1·29	2·04	1·86	1·56	1·47	1·82	1·42	1·52	1·42
Iron and Aluminium (Fe_2O_3) Al_2O_3	5·58 7·31	5·20 7·06	5·36 7·22	4·86 6·98	4·92 7·16	5·40 7·88	4·96 7·86	5·71 8·65	5·88 8·52
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·066	0·064	0·063	0·056	0·042	0·051	0·087	0·046	0·078

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	HISSAR								
DESCRIPTION	1st ft. Black soil							1st ft.	2nd ft.
Number	90	91	92	93	94	95	96	97	98
Mechanical.									
Fine gravel	0·76	*nil*	*nil*	0·43	0·08	0·12	0·26	*nil*	*nil*
Coarse sand	16·96	·41	1·30	0·60	0·46	4·46	0·12	2·51	2·42
Fine sand	20·18	60·28	65·55	62·38	66·08	59·12	36·40	60·41	59·00
Silt	16·74	9·89	9·29	10·11	11·39	11·59	9·75	11·35	10·24
Fine silt	25·60	9·44	9·12	9·28	11·20	8·32	14·88	7·68	9·12
Clay	19·20	15·52	13·44	12·80	14·72	11·20	33·44	16·48	21·76
Chemical.									
Potash as K_2O	0·761	1·680	0·495	0·640	0·717	0·710	1·279	0·682	0·627
Phosphoric acid as P_2O_5	0·073	0·155	0·113	0·160	0·138	0·140	0·118	0·316	0·316
Lime as CaO	3·44	·825	·985	2·040	·920	1·045	·890	2·02	2·36
Magnesia as MgO	2·10	1·648	·863	1·070	·865	1·370	·619	1·34	1·39
Iron and Aluminium (Fe_2O_3) Al_2O_3	5·94 8·80	8·335	8·112	8·415	8·752	8·725	15·642	3·28 4·58	3·56 5·96
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·052	0·053	0·039	0·042	0·053	0·039	0·049	0·074	0·042

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	HISSAR									
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.				
Number	99	100	101	102	103	104	105	106	107	108
Mechanical.										
Fine gravel	0·04	*nil*	*nil*	*nil*	0·07	0·04	0·45	0·22	0·20	*nil*
Coarse sand	7·85	9·16	1·48	0·86	0·62	0·50	2·24	2·02	0·33	0·52
Fine sand	47·05	42·84	33·91	27·87	60·77	53·85	47·25	53·50	49·47	58·14
Silt	14·38	13·29	17·24	15·87	16·85	20·51	19·40	16·20	15·98	14·40
Fine silt	13·76	14·08	19·36	20·32	9·28	10·24	15·85	14·45	19·88	11·68
Clay	18·40	21·28	26·08	36·64	14·24	15·52	15·30	13·28	15·84	15·66
Chemical.										
Potash as K_2O	0·666	0·591	0·736	0·771	0·570	0·382	0·91	1·01	0·94	0·64
Phosphoric acid as P_2O_5	0·236	0·226	0·185	0·166	0·218	0·205	0·149	0·319	0·148	0·149
Lime as CaO	2·65	2·61	1·37	1·12	1·16	1·31	1·11	1·23	1·11	0·78
Magnesia as MgO	1·17	1·62	1·49	1·27	0·53	0·63	0·69	0·69	0·75	0·66
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·10 6·74	4·20 6·10	4·96 6·99	5·12 8·00	7·48 1·36	5·60 3·29	4·04 4·71	3·84 5·88	4·08 5·50	3·80 5·59
Potash (available)	..	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil).	0·081	0·054	0·063	0·048	0·038	0·043	0·048	0·054	0·050	0·042

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	HISSAR	KARNAL							
DESCRIPTION Number	109	110	111	112	113	114	115	116	117
Mechanical.									
Fine gravel	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*
Coarse sand	0·40	9·84	2·38	1·84	9·15	9·96	29·32	2·83	·49
Fine sand	58·35	40·32	46·05	26·50	66·00	15·90	62·30	40·90	32·30
Silt	13·22	15·38	18·17	32·30	14·10	38·95	3·10	29·38	34·10
Fine silt	12·88	17·92	18·24	34·32	5·08	26·04	1·12	13·76	18·84
Clay	16·60	14·72	16·16	8·68	1·48	10·60	1·36	6·48	8·56
Chemical.									
Potash as K_2O	0·79	0·873	0·883	..	..	..	..	..	..
Phosphoric acid as P_2O_5	0·128	0·363	0·385	..	..	..	..	..	..
Lime as CaO	0·62	2·170	1·275	..	..	..	..	..	..
Magnesia as MgO	0·61	1·292	1·549	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	3·68 4·85	8·742	8·820	..	..	..	..	..	..
Potash (available)	..	..	..	·031	·026	·027	·025	·037	·047
Phosphoric (available)	..	..	..	·012	·007	·013	·009	·006	·009
NITROGEN (% on air dried soil)	0·030	0·051	0·047	0·066	0·024	0·074	0·011	0·080	0·074

TABLE I—*contd.*

Analysis of the Punjab Soils—contd.

LOCALITY	KARNAL								FEROZE-PUR
DESCRIPTION		1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.		
Number	118	119	120	121	122	123	124	125	126
Mechanical.									
Fine gravel	*nil*	·21	·08	·05	·17	·06	·14	*nil*	*nil*
Coarse sand	2·06	1·68	1·10	1·74	1·41	1·09	1·13	21·0	7·90
Fine sand	13·80	46·73	40·74	47·29	42·64	42·45	44·37	36·62	26·84
Silt	26·86	20·91	19·96	18·67	17·13	22·98	18·81	25·18	26·67
Fine silt	30·82	16·16	16·96	13·92	16·56	15·76	16·00	10·86	17·75
Clay	19·12	9·44	16·64	16·96	12·96	9·44	14·88	7·52	14·56
Chemical.									
Potash as K_2O	..	0·65	0·65	0·67	0·91	1·10	0·88	0·64	1·090
Phosphoric acid as P_2O_5	..	0·13	0·10	0·12	0·14	0·14	0·13	0·13	0·235
Lime as CaO	..	0·58	0·44	0·43	0·78	0·84	0·63	1·09	4·130
Magnesia as MgO	..	1·43	1·43	1·34	1·28	1·38	1·45	0·46	2·645
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	4·08 4·86	4·20 4·75	4·08 5·02	3·42 7·31	3·47 6·57	3·47 7·31	3·04 3·98	11·115
Potash (available)	·022	..	..	..	..	..	..	..	..
Phosphoric (available)	·014	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·112	0·064	0·056	0·07	0·059	0·088	0·071	0·039	0·101

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	FEROZEPUR					JULLUNDUR		LAHORE	
DESCRIPTION		1st ft.	2nd ft.	1st ft.	2nd ft.				
Number	127	128	129	130	131	132	133	134	135
Mechanical.									
Fine gravel	*nil*	*nil*	0·67	0·21	0·14	*nil*	*nil*	*nil*	*nil*
Coarse sand	12·64	3·82	3·58	2·40	1·84	33·46	1·82	3·88	2·01
Fine sand	15·36	40·47	35·30	41·17	27·63	36·56	6·22	46·08	45·63
Silt	19·90	20·30	26·03	20·04	25·98	11·82	17·65	20·64	22·88
Fine silt	34·71	15·76	18·32	17·68	24·16	9·00	38·28	12·16	12·16
Clay	14·74	13·60	13·76	13·92	15·52	6·90	28·08	12·48	15·04
Chemical.									
Potash as K_2O	0·867	0·775	0·786	0·721	0·763	0·786	1·459	0·790	0·930
Phosphoric acid as P_2O_5	0·287	0·206	0·225	0·225	0·209	0·211	0·160	0·128	0·102
Lime as CaO	1·180	4·71	5·61	5·08	6·09	..	..	0·960	1·240
Magnesia as MgO	1·565	1·94	1·67	1·88	1·53	..	..	1·280	1·190
Iron and Aluminium (Fe_2O_3) Al_2O_3	12·843	4·24 5·83	4·32 5·98	4·16 5·49	4·69 5·97	..	..	10·822	11·518
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·053	0·078	0·066	0·066	0·065	0·046	0·164	0·034	0·044

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHEIKHUPURA								
DESCRIPTION Number	136	137	138	139	140	141	142	143	144
Mechanical.									
Fine gravel	·39	·52	..	..	..	..	..	..	..
Coarse sand	15·74	23·20	..	..	..	..	..	..	..
Fine sand	36·73	36·24	..	..	..	..	..	..	..
Silt	16·18	17·58	..	..	..	..	..	..	..
Fine silt	9·92	8·00	..	..	..	..	..	..	..
Clay	16·96	7·52	..	..	..	..	..	..	..
Chemical.									
Potash as K_2O	0·710	0·290	0·205	0·165	0·588	0·329	0·825	1·142	0·196
Phosphoric acid as P_2O_5	0·128	0·114	0·158	0·147	0·093	0·131	0·196	0·254	0·138
Lime as CaO	1·330	3·250	0·812	0·588	0·658	0·735	2·910	0·784	0·497
Magnesia as MgO	0·925	1·940	1·09	0·940	1·310	0·850	1·430	1·520	0·750
Iron and Aluminium (Fe_2O_3) Al_2O_3	11·022	5·736	1·98 2·26	1·78 3·18	3·26 5·72	1·86 3·05	4·33 6·11	4·44 2·18	1·28 2·81
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·036	0·042	0·021	0·030	0·033	0·028	0·077	0·064	0·023

TABLE I—*contd.*

Analysis of the Punjab Soils—contd.

LOCALITY	SHEIKHUPURA					GUJRAT			MONTGOMERY
DESCRIPTION Number	145	146	147	148	149	150	151	152	153
Mechanical.									
Fine gravel	..	..	..	..	..	*nil*	*nil*	*nil*	·22
Coarse sand	..	..	..	..	..	14·79	59·77	8·61	·76
Fine sand	..	..	..	..	..	26·83	20·49	29·64	39·42
Silt	..	..	..	..	..	25·15	7·25	26·19	15·08
Fine silt	..	..	..	..	..	12·80	2·24	17·92	19·60
Clay	..	..	..	..	..	14·08	4·64	13·44	17·60
Chemical.									
Potash as K_2O	0·791	0·330	0·536	0·727	0·899	0·760	0·372	0·702	..
Phosphoric acid as P_2O_5	0·084	0·115	0·118	0·198	0·148	0·225	0·159	0·290	..
Lime as CaO	1·386	1·547	0·609	2·450	2·303	1·230	·835	1·210	1·68
Magnesia as MgO	1·30	1·66	0·88	1·15	2·46	1·600	1·000	1·020	0·25
Iron and Aluminium (Fe_2O_3) Al_2O_3	3·26 5·74	4·10 6·30	1·94 3·41	4·42 5·43	3·82 7·36	10·715	6·741	10·420	11·91
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·043	0·060	0·031	0·097	0·090	0·073	0·007	0·082	..

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MONTGOMERY								
DESCRIPTION Number	154*	155	156	157	158	159	160	161	162
Mechanical.									
Fine gravel	..	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	1·20	1·00
Coarse sand	..	2·60	2·81	..	2·06	2·44	1·35	3·97	2·54
Fine sand	..	12·85	48·62	..	50·59	59·27	49·12	57·43	46·43
Silt	..	20·30	23·43	..	16·89	11·89	24·29	11·26	20·63
Fine silt	..	35·00	11·84	..	16·47	14·99	12·29	15·60	13·85
Clay	..	25·12	10·88	..	12·40	11·40	11·44	11·54	12·43
Chemical.									
Potash as K_2O	..	..	0·780	0·950	0·81	0·72	0·63	0·76	0·78
Phosphoric acid as P_2O_5	..	..	0·150	0·288	0·187	0·210	0·226	0·208	0·185
Lime as CaO	..	..	3·160	4·800	5·63	5·14	3·64	6·12	5·05
Magnesia as MgO	..	..	2·010	2·900	1·46	1·92	1·89	1·82	1·94
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	9·300	8·830	3·68 5·20	3·20 5·27	4·00 4·54	3·76 4·47	3·96 4·97
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN ([illegible])	..	..	0·024	0·037	0·027	0·033	0·054	0·034	0·048

* Cancelled.

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MONTGOMERY								
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.
Number	163	164	165	166	167	168	169	170	171
Mechanical.									
Fine gravel	0·04	0·04	*nil*	0·03	0·03	0·07	0·07	0·1	0·03
Coarse sand	2·51	2·56	1·91	1·08	2·07	2·10	2·31	2·60	0·46
Fine sand	56·32	52·47	43·19	38·07	55·60	51·56	53·97	54·36	45·90
Silt	19·16	18·52	26·16	28·06	17·42	18·90	18·89	17·29	19·89
Fine silt	10·72	12·48	12·31	16·98	11·79	12·73	13·12	12·66	15·94
Clay	11·72	13·48	14·59	15·87	12·78	14·72	11·65	10·24	18·72
Chemical.									
Potash as K_2O	0·90	0·85	1·04	1·05	0·77	0·80	0·84	0·77	0·99
Phosphoric acid as P_2O_5	0·207	0·182	0·200	0·157	0·205	0·170	0·183	0·153	0·212
Lime as CaO	3·05	3·57	4·26	5·68	3·00	3·88	4·17	5·56	3·88
Magnesia as MgO	1·83	1·82	1·04	1·09	1·79	1·79	1·78	1·77	2·04
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·20 4·83	4·28 5·19	4·40 5·55	4·44 5·79	4·12 4·66	4·40 4·53	4·04 4·29	4·10 4·74	4·60 5·21
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·024	0·038	0·039	0·016	0·028	0·032	0·040	0·035	0·038

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MONTGOMERY	LYALLPUR							
DESCRIPTION	2nd ft.								
Number	172	173	174	175	176	177	178	179	180
Mechanical.									
Fine gravel	0·04	0·34	..	..	..	..	..	..	..
Coarse sand	0·96	8·24	..	..	..	..	..	..	..
Fine sand	47·48	41·32	..	..	..	..	..	..	..
Silt	19·41	18·63	..	..	..	..	..	..	..
Fine silt	13·70	18·70	..	..	..	..	..	..	..
Clay	18·05	10·95	..	..	..	..	..	..	..
Chemical.									
Potash as K_2O	1·12	0·827	1·250	1·030	1·030	1·190	1·200	0·960	0·780
Phosphoric acid as P_2O_5	0·187	0·351	0·210	0·160	0·150	0·200	0·180	0·140	0·140
Lime as CaO	4·28	6·280	..	..	..	..	..	..	..
Magnesia as MgO	2·12	0·885	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·64 5·54	9·989	..	..	..	..	..	..	..
Potash (available)	..	..	0·009	0·028	0·023	0·012	0·023	0·024	0·020
Phosphoric (available)	..	..	0·048	0·049	0·053	0·074	0·048	0·030	0·024
NITROGEN (% on air dried soil)	0·027	0·041	0·043	0·038	0·038	0·052	0·047	0·038	0·026

TABLE 1—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	LYALLPUR					SHAHPUR			
						Sargodha			
Description		1st ft.	2nd ft.	1st ft.	2nd ft.				
Number	181	182	183	184	185	186	187	188	189
Mechanical.									
Fine gravel	..	*nil*	*nil*	*nil*	*nil*	0·06	*nil*	*nil*	..
Coarse sand	..	13·01	7·60	23·03	25·55	17·63	10·89	13·91	..
Fine sand	..	43·80	46·77	46·22	44·73	45·07	44·32	39·39	..
Silt	..	14·65	15·46	11·35	8·85	15·63	13·51	17·86	..
Fine silt	..	13·20	16·21	9·15	7·84	8·00	14·24	11·20	..
Clay	..	15·60	14·40	10·14	10·64	7·04	13·92	12·64	..
Chemical.									
Potash as K_2O	·760	0·500	0·600	0·550	0·600	0·956	0·743	..	..
Phosphoric acid as P_2O_5	·140	0·227	0·210	0·224	0·230	0·215	1·611	0·281	..
Lime as CaO	..	4·27	4·56	1·64	1·87	3·430	3·450	3·220	16·98
Magnesia as MgO	..	1·55	1·59	1·16	1·31	1·860	1·290	1·710	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	2·38 5·28	2·52 5·57	2·63 4·40	2·27 4·30	9·895	8·024	8·689	..
Potash (available)	0·029	..	..	..	..	..	..	..	0·164
Phosphoric (available)	0·012	..	..	..	..	..	..	..	0·007
NITROGEN (% on air dried soil)	·049	0·042	0·043	0·029	0·027	0·033	0·037	0·042	0·014

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHAHPUR								
DESCRIPTION	SARGODHA							MONA	
Number	190	191	192	193	194	195	196	197	198
Mechanical.									
Fine gravel	..	..	..	..	..	..	..	*nil*	0·02
Coarse sand	..	.	..	..	..	..	..	3·59	2·93
Fine sand	..	..	..	..	..	..	..	23·36	18·29
Silt	..	..	..	..	..	..	..	28·46	25·16
Fine silt	..	..	..	..	..	..	..	18·48	22·88
Clay	..	..	..	..	..	..	..	21·12	25·60
Chemical.									
Potash as K_2O	..	..	..	..	..	..	..	0·884	0·956
Phosphoric acid as P_2O_5	..	..	..	..	..	..	..	0·154	0·144
Lime as CaO	..	..	..	..	..	..	..	1·78	1·88
Magnesia as MgO	.	..	..	..	..	..	..	2·01	1·80
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	..	..	..	..	..	2·64 10·19	5·68 8·59
Potash (available)	0·033	0·067	0·078	0·035	0·057	0·036	0·035	..	..
Phosphoric (available)	0·067	0·161	0·028	0·031	0·009	0·057	0·059	..	..
NITROGEN (% on air dried soil)	.	..	..	..	..	..	..	0·076	0·049

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHAHPUR								
	Mona							Sargodha.	
Description	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	•	1st ft.	2nd ft.
Number	199	200	201	202	203	204	205	206	207
Mechanical.									
Fine gravel	0·13	0·01	0·52	0·40	*nil*	0·01	0·44	0·16	*nil*
Coarse sand	7·90	8·01	43·46	43·31	5·41	4·14	5·23	8·08	5·65
Fine sand	25·21	18·10	21·14	20·32	24·58	22·33	22·39	35·50	36·46
Silt	18·56	17·38	11·77	10·33	24·39	22·37	24·57	21·05	21·10
Fine silt	12·96	20·15	7·60	10·08	17·76	22·96	24·27	15·36	15·04
Clay	28·64	32·32	10·72	9·44	23·69	23·84	22·08	15·84	15·36
Chemical.									
Potash as K_2O	0·549	0·901	0·397	0·343	1·079	0·901	1·02	0·693	0·893
Phosphoric acid as P_2O_5	0·165	0·171	0·149	0·121	0·233	0·239	0·238	0·233	0·190
Lime as CaO	1·05	1·84	6·17	4·62	1·22	1·15	3·20	2·84	3·26
Magnesia as MgO	0·75	1·58	1·46	1·40	1·95	1·77	1·57	1·62	1·71
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·72 8·53	5·72 8·53	3·44 4·68	3·64 4·10	5·38 7·96	5·77 8·76	3·89 8·25	4·44 6·86	4·90 6·88
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·085	0·068	0·053	0·081	0·043	0·061	0·056	0·055	0·045

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHAHPUR						JHANG		MULTAN
	SARGODHA								
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.			
Number	208	209	210	211	212	213	214	215	216
Mechanical.									
Fine gravel	0·28	1·08	0·09	0·43	0·12	*nil*	*nil*	*nil*	*nil*
Coarse sand	3·52	2·82	42·50	38·43	7·18	3·41	9·44	8·00	7·36
Fine sand	27·74	21·22	26·03	24·78	24·09	22·56	12·00	12·64	14·92
Silt	23·10	20·83	10·90	12·58	30·82	33·74	20·80	22·69	22·58
Fine silt	19·52	21·04	8·64	10·08	19·04	19·44	48·73	46·31	47·69
Clay	20·96	26·40	8·00	8·43	16·00	16·96	5·58	4·90	3·78
Chemical.									
Potash as K_2O	0·724	1·057	0·547	0·495	0·689	0·585	0·847	0·837	0·442
Phosphoric acid as P_2O_5	0·264	0·176	0·182	0·208	0·156	0·207	0·640	0·622	0·533
Lime as CaO	3·06	4·18	4·28	5·43	7·30	9·20	4·400	4·160	4·520
Magnesia as MgO	1·65	2·01	1·34	1·45	2·24	2·49	1·600	0·770	1·320
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·85 7·24	5·72 8·27	3·76 5·13	3·79 5·10	5·05 6·10	4·88 5·63	8·445	9·758	8·152
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·067	0·060	0·039	0·040	0·071	0·046	0·053	0·047	0·053

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MULTAN								
DESCRIPTION		Ghasree	Ghasra	Ratti	Ratta			1st ft.	2nd ft.
Number	217	218	219	220	221	222	223	224	225
Mechanical.									
Fine gravel	0·12	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*
Coarse sand	1·10	4·54	1·93	2·29	·87	15·51	33·08	·40	·30
Fine sand	14·22	52·34	37·36	27·84	34·08	52·45	50·70	16·74	11·56
Silt	31·79	15·09	26·08	29·20	35·39	12·60	6·78	6·99	5·05
Fine silt	30·40	17·04	24·74	26·72	22·83	5·68	4·48	7·84	7·12
Clay	14·72	10·32	11·52	11·05	9·09	8·64	3·44	63·60	71·04
Chemical.									
Potash as K_2O	0·717	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5	0·242	..	..	..	..	..	..	..	..
Lime as CaO	3·060	..	..	..	..	..	..	..	..
Magnesia as MgO	1·230	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	10·738	..	..	..	..	..	..	..	..
Potash (available)	..	0·019	0·050	0·043	0·034	..	..	..	..
Phosphoric (available)	..	0·051	0·024	0·031	0·032	..	..	..	..
NITROGEN (% on air dried soil)	0·064	0·114	0·127	0·134	0·139	..	..	..	..

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MULTAN				MUZAFFARGARH		DERA GHAZI KHAN		BAHAWALPUR
DESCRIPTION	1st ft.	2nd ft.							
Number	226	227	228	229	230	231	232	233	234
Mechanical.									
Fine gravel	0·24	*nil*	..	..	*nil*	*nil*	*nil*	*nil*	0·66
Coarse sand	1·85	3·17	..	..	5·01	4·08	18·03	40·82	2·45
Fine sand	32·01	24·64	..	..	33·52	31·47	56·12	18·72	42·15
Silt	8·95	10·29	..	..	20·79	22·02	4·71	9·93	26·12
Fine silt	10·88	10·80	..	..	20·32	12·32	6·08	10·24	12·80
Clay	39·04	43·52	..	..	20·32	13·28	9·28	16·48	8·96
Chemical									
Potash as K_2O	..	..	0·675	0·808	0·861	0·822	0·687	0·802	..
Phosphoric acid as P_2O_5	..	..	0·169	0·159	0·195	0·223	0·670	1·355	..
Lime as CaO	..	..	2·786	2·786	5·090	6·015	9·980	6·030	..
Magnesia as MgO	..	..	1·56	1·63	1·948	1·991	1·170	1·730	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	4·46 5·99	4·92 6·14	11·745	10·737	9·155	8·295	..
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	..	..	..	..	0·043	0·045	0·026	0·040	..

TABLE I (*a*).

The Punjab Soils.

SUBSOILS.

Soil No.	Nitrogen	Organic matter	Lime CaO	Potash K_2O	Phosphates P_2O_5	Remarks
			Per cent. on air dried material			
			GURDASPUR.			
48	0·059	3·21	0·56	0·52	0·10	Soil.
49	0·066	3·83	0·28	0·57	0·11	Subsoil.
50	0·075	2·16	0·84	0·43	0·08	Soil.
51	0·043	2·82	0·85	0·53	0·06	Subsoil.
52	0·033	1·78	0·41	0·48	0·16	Soil.
53	0·066	1·87	0·39	0·44	0·14	Subsoil.
			RAWALPINDI			
54	0·067	3·63	11·44	0·70	0·20	Soil.
55	0·086	4·26	10·13	0·59	0·18	Subsoil.
56	0·041	2·44	11·20	0·50	0·21	Soil.
57	0·048	2·71	11·39	0·51	0·21	Subsoil.
58	0·059	2·90	9·07	0·30	0·16	Soil.
59	0·046	4·33	9·55	0·45	0·17	Subsoil.
			ATTOCK.			
60	0·053	5·17	1·95	0·77	0·17	Soil.
31	0·050	6·31	1·99	0·88	0·19	Subsoil.
63	0·071	9·04	12·81	0·55	0·10	Soil.
64	0·055	9·27	12·88	0·46	0·15	Subsoil.
66	0·037	5·62	7·71	0·42	0·11	Soil.
67	0·037	8·20	8·37	0·41	0·17	Subsoil.
69	0·093	6·96	8·89	0·20	0·16	Soil.

TABLE I (*a*)—*contd.*

The Punjab Soils—contd.

SUBSOILS—*contd.*

Soil No.	Nitrogen	Organic matter	Lime Ca O	Potash K_2O	Phosphates P_2O_5	Remarks
			Per cent. on air dried material			
			ATTOCK—*contd.*			
70	0·054	6·31	2·39	0·62	0·10	Subsoil.
72	0·047	5·86	5·89	0·52	0·10	Soil.
73	0·049	6·64	4·51	0·54	0·09	Subsoil.
75	0·090	9·65	9·14	0·68	0·37	Soil.
76	0·062	10·02	8·85	0·72	0·28	Subsoil.
78	0·069	8·76	8·20	0·63	0·26	Soil.
79	0·067	10·57	10·92	0·49	0·16	Subsoil.
81	0·066	7·33	12·18	0·52	0·20	Soil.
82	0·064	9·21	11·31	0·80	0·10	Subsoil.
84	0·056	7·51	13·20	0·87	0·12	Soil.
85	0·042	8·25	16·60	0·84	0·08	Subsoil.
87	0·087	10·31	5·10	0·76	0·04	Soil.
88	0·046	8·67	6·16	0·81	0·04	Subsoil.
			HISSAR.			
97	0·074	3·46	2·02	0·68	0·32	Soil.
98	0·042	3·58	2·36	0·63	0·32	Subsoil.
99	0·081	3·43	2·65	0·67	0·24	Soil.
100	0·054	4·67	2·61	0·59	0·23	Subsoil.
101	0·063	3·27	1·37	0·74	0·19	Soil.
102	0·048	4·84	1·12	0·77	0·17	Subsoil.
103	0·038	2·85	1·16	0·57	0·22	Soil.
104	0·043	2·89	1·31	0·38	0·21	Subsoil.

Table I(*a*)—*contd.*

The Punjab Soils—contd.

Subsoils—*contd*

Soil No.	Nitrogen	Organic matter	Lime CaO	Potash K_2O	Phosphates P_2O_5	Remarks
			Per cent. on air dried material			
			Karnal.			
119	0·064	..	0·58	0·65	0·13	Soil.
120	0·056	·16	0·41	0·65	0·10	Subsoil.
121	0·070	3·52	0·43	0·67	0·12	Soil.
122	0·059	3·18	0·78	0·91	0·14	Subsoil.
123	0·088	3·12	0·84	1·10	0·14	Soil.
124	0·071	4·28	0·63	0·88	0·13	Sub-soil.
			Ferozepur.			
128	0·078	5·86	4·71	0·78	0·21	Soil.
129	0·066	6·57	5·61	0·79	0·23	Subsoil.
130	0·066	6·13	5·08	0·72	0·23	Soil.
131	0·065	7·13	6·09	0·76	0·21	Subsoil.
			Montgomery.			
163	0·034	1·73	3·05	0·90	0·21	Soil.
164	0·038	0·95	3·57	0·85	0·18	Subsoil.
165	0·039	1·57	1·26	1·04	0·20	Soil.
166	0·016	3·15	5·68	1·05	0·16	Subsoil.
167	0·028	1·68	3·00	0·77	0·21	Soil.
168	0·032	1·10	3·88	0·80	0·17	Subsoil.
169	0·040	2·42	1·17	0·84	0·18	Soil.
170	0·035	1·75	5·56	0·77	0·15	Subsoil.
171	0·038	1·58	3·88	0·99	0·21	Soil.
172	0·027	3·32	4·28	1·12	0·19	Subsoil.

Table I(*a*)—*concld.*

The Punjab Soils—concld.

Subsoils—*concld.*

Soil No.	Nitrogen	Organic matter	Lime CaO	Potash K_2O.	Phosphates P_2O_5	Remarks
			Per cent. on air dried material.			
			Lyallpur.			
182	0·012	3·01	4·27	0·50	0·23	Soil.
183	0·013	0·80	1·56	0·60	0·21	Subsoil.
184	0·029	1·21	1·61	0·55	0·22	Soil.
185	0·027	0·87	1·87	0·60	0·23	Subsoil.
			Shahpur.			
197	0·076	5·60	1·78	0·88	0·15	Soil.
198	0·019	..	1·88	0·96	0·14	Subsoil.
199	0·085	5·45	1·05	0·55	0·17	Soil.
200	0·068	6·46	1·84	0·90	0·17	Subsoil.
201	0·053	3·40	6·17	0·40	0·15	Soil.
202	0·084	6·12	1·62	0·34	0·12	Subsoil.
203	0·013	1·01	1·22	1·08	0·23	Soil.
204	0·084	5·17	1·55	0·90	0·24	Subsoil.
206	0·055	1·74	2·84	0·69	0·23	Soil.
207	0·045	6·70	3·26	0·89	0·19	Subsoil.
208	0·067	7·00	3·06	0·72	0·26	Soil.
209	0·060	1·92	4·18	1·06	0·17	Subsoil.
210	0·039	3·39	4·28	0·55	0·18	Soil.
211	9·040	2·31	5·43	0·50	0·21	Subsoil.
212	0·071	5·89	7·30	0·69	0·16	Soil.
213	0·046	1·82	9·20	0·59	0·21	Subsoil.

Table II.

The Punjab Soils.

Soil analyses.

(Water Extract 10 per cent.)

Soil No.	Total solids	Carbonates as $Na_2 Co_3$	Bicarbonates as $NaH Co_3$	Chlorides as $Na Cl$	Sulphates as $Na_2 So_4$
		Per cent. on air dried material			
		Ambala.			
10	0·110	*Nil*	0·084	0·060	*Nil*
11	0·060	,,	0·067	0·007	,,
12	0·080	,,	0·084	0·005	,,
		Rawalpindi.			
54	0·131	*Nil*	0·084	0·019	*Nil*
55	0·129	,,	0·084	0·012	,,
56	0·188	,,	0·103	0·020	0·073
57	0·223	,,	0·124	0·034	0·092
58	0·301	,,	0·239	0·071	*Nil*
59	0·078	,,	0·076	0·008	,,
		Attock.			
60	0·562	*Nil*	0·235	0·105	0·233
61	0·516	,,	0·202	0·082	0·202
62	0·350	,,	0·185	0·105	0·089
63	0·452	,,	0·185	0·094	0·101
64	0·240	,,	0·185	0·070	0·074
65	0·200	,,	0·185	0·070	0·074
66	0·210	,,	0·202	0·058	0·075
67	0·320	,,	0·220	0·058	0·107
68	0·240	,,	0·220	0·058	0·087
69	0·320	,,	0·220	0·070	0·098

TABLE II—*contd.*

The Punjab Soils—contd.

SOIL ANALYSES—*contd.*

(Water Extract 10 per cent.)

Soil No.	Total solids	Carbonates as $Na_2 Co_3$	Bicarbonates as $NaH Co_3$	Chlorides as $Na Cl$	Sulphates as $Na_2 So_4$
		Per cent. on air dried material			
		ATTOCK—*contd.*			
70	0·310	*Nil*	0·185	0·070	0·072
71	0·376	,,	0·202	0·070	0·073
72	0·296	,,	0·286	0·045	0·063
73	0·260	,,	0·269	0·058	0·064
74	0·320	,,	0·269	0·058	0·052
75	0·478	,,	0·269	0·081	0·064
76	0·412	,,	0·302	0·081	0·124
77	0·510	,,	0·252	0·058	0·158
78	0·284	,,	0·252	0·058	0·064
79	0·224	,,	0·252	0·058	0·104
80	0·290	,,	0·269	0·081	0·090
81	0·320	,,	0·269	0·046	0·044
82	0·400	,,	0·252	0·070	0·070
83	0·240	,,	0·252	0·047	0·055
84	0·280	,,	0·252	0·047	0·064
85	0·440	,,	0·252	0·070	0·085
86	0·488	,,	0·252	0·055	0·147
87	0·298	,,	0·202	0·046	0·049
88	0·377	,,	0·218	0·093	0·066
89	0·364	,,	0·235	0·070	0·061
90	0·320	,,	0·202	0·035	0·048
91	0·426	,,	0·286	0·082	0·051

TABLE II—*contd.*

The Punjab Soils—contd.

SOIL ANALYSES—*contd.*

(Water Extract 10 per cent.)

Soil No.	Total solids	Carbonates as $Na_2 Co_3$	Bicarbonates as $Na HCo_3$	Chlorides as $Na Cl$	Sulphates as $Na_2 So_4$
			Per cent. on air dried material		
			HISSAR.		
97	0·534	*Nil*	0·373	0·034	0·063
98	0·535	,,	0·415	0·034	0·038
99	0·482	,,	0·380	0·017	0·023
100	0·458	,,	0·363	0·045	0·035
			KARNAL.		
119	0·069	*Nil*	0·067	0·010	*Nil*
120	0·127	,,	0·050	0·005	0·038
121	0·070	,,	0·031	0·002	*Nil*
122	0·078	,,	0·031	0·015	,,
123	0·117	,,	0·050	0·023	0·029
124	0·093	,,	0·050	0·005	0·006
			FEROZEPUR.		
128	0·303	*Nil*	0·118	0·060	0·044
129	0·210	,,	0·118	0·015	0·080
130	0·270	,,	0·101	0·012	0·014
131	0·301	,,	0·101	0·024	0·021
			MONTGOMERY.		
158	0·381	*Nil*	0·235	0·055	0·057
159	0·317	,,	0·219	0·064	*Nil*
160	0·321	,,	0·199	0·055	,,

TABLE II—*concld.*

The Punjab Soils—concld.

SOIL ANALYSES—*concld.*

(Water Extract 10 per cent.)

Soil No.	Total solids	Carbonates as $Na_2\ Co_3$	Bicarbonates as $NaH\ Co_3$	Chlorides as $Na\ Cl$	Sulphates as $Na_2\ So_4$
			Per cent. on air dried material		
			MONTGOMERY—*contd.*		
161	0·276	*Nil*	0·190	0·041	*Nil*
162	0·288	,,	0·185	0·035	,,
			SHAHPUR (MONA).		
197	0·073	*Nil*	0·050	0·007	*Nil*
198	0·065	,,	0·057	0·012	,,
199	0·174	,,	0·050	0·023	0·075
200	0·067	,,	0·050	0·007	0·020
201	0·126	,,	0·076	0·012	*Nil*
202	0·206	,,	0·071	0·014	0·087
203	0·111	,,	0·067	0·007	*Nil*
204	0·093	,,	0·067	0·013	0·008
			SHAHPUR (SARGODHA).		
206	0·109	*Nil*	0·084	0·105	*Nil*
207	0·330	,,	0·260	0·054	,,
208	0·392	,,	0·252	0·095	,,
209	0·108	,,	0·076	0·013	,,
210	0·341	,,	0·252	0·066	,,
211	0·094	,,	0·076	0·007	,,
212	0·137	,,	0·100	0·016	,,
213	0·138	,,	0·084	0·016	,,

TABLE III.

The Punjab Soils.

MECHANICAL ANALYSES OF LYALLPUR SUBSOIL DOWN TO WATER TABLE.

No.	Description	Fine gravel	Coarse sand	Fine sand	Silt	Fine silt	Clay
			Per cent. on air dried earth				
1	1st and 2nd foot of soil.	0·15	6·95	36·21	18·10	16·40	8·58
2	3rd and 4th foot of soil.	0·16	2·05	37·81	22·76	16·62	8·66
3	5th and 6th foot of soil.	0·39	1·52	43·24	22·43	15·45	7·32
4	7th and 8th foot of soil.	*Nil*	2·02	47·35	21·56	14·05	6·92
5	9th and 10th foot of soil.	0·01	2·79	51·32	19·04	11·70	6·46
6	11th and 12th foot of soil.	*Nil*	13·93	77·88	2·98	4·00	Trace
7	13th and 14th foot of soil.	,,	27·91	64·54	2·78	4·00	1·13
8	15th and 16th foot of soil.	,,	44·32	47·78	2·93	4·20	Trace
9	17th and 18th foot of soil.	,,	59·39	29·14	4·44	0·54	1·35
10	19th and 20th foot of soil.	,,	28·16	62·67	2·58	4·60	1·09
11	21st and 22nd foot of soil.	,,	42·66	46·24	5·43	4·50	1·26
12	23rd and 24th foot of soil.	,,	63·03	29·06	3·70	0·27	0·59
13	25th and 26th foot of soil.	,,	64·65	27·03	3·62	3·60	0·58
14	27th and 28th foot of soil.	,,	62·39	30·99	3·03	3·20	*Nil*
15	29th and 30th foot of soil.	,,	78·16	17·15	2·08	3·40	,,
16	31st and 32nd foot of soil.	,,	60·05	29·40	4·29	0·44	1·11

Table III—*contd.*

The Punjab Soils—contd.

MECHANICAL ANALYSES OF LYALLPUR SUBSOIL DOWN TO WATER TABLE—*contd.*

No.	Description	Fine gravel	Coarse sand	Fine sand	Silt	Fine silt	Clay
		Per cent. on air dried earth					
17	33rd and 34th foot of soil.	..	..	..	..	..	..
18	35th and 36th foot of soil.	*Nil*	3·38	7·07	28·23	38·20	19·20
19	37th and 38th foot of soil.	,,	64·95	23·00	4·20	6·90	*Nil*
20	39th and 40th foot of soil.	,,	42·94	44·04	5·35	0·47	1·20
21	41st and 42nd foot of soil.	0·55	56·80	31·24	3·06	5·00	1·62
22	43rd and 44th foot of soil.	0·40	44·96	42·53	5·50	0·52	1·48
23	45th and 46th foot of soil.	*Nil*	37·61	40·98	5·59	4·80	1·56
24	47th and 48th foot of soil.	0·42	40·76	38·32	5·29	7·40	4·69
25	49th and 50th foot of soil.	0·26	64·99	25·52	2·51	7·20	0·88
26	51st and 52nd foot of soil.	*Nil*	79·74	12·23	1·52	2·20	*Nil*
27	53rd and 54th foot of soil.	9·48	43·18	16·13	7·98	17·80	4·24
28	55th and 56th foot of soil.	1·55	18·06	31·10	7·95	10·10	3·02
29	57th and 58th foot of soil.	0·08	0·83	39·80	33·89	18·00	6·64
30	59th and 60th foot of soil.	0·06	5·12	34·19	30·99	22·00	7·20
31	61st and 62nd foot of soil.	*Nil*	44·03	39·55	7·04	8·30	*Nil*
32	63rd and 64th foot of soil.	,,	65·71	26·06	3·70	0·44	0·58
33	65th and 66th foot of soil.	,,	43·44	32·52	5·45	6·40	1·84

Table IV.

The Punjab Soils.

Nitrogen and Organic matter.

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
Kangra.			
1	0·05	..	..
2	0·15	..	..
3	0·076	..	..
4	0·05	..	..
5	0·11	..	..
6	0·11	8·64	0·013
7	0·10	2·17	0·016
Ambala.			
8	0·02	2·09	0·019
9	0·054	3·09	0·018
10	0·061	3·11	0·020
11	0·039	2·41	0·016
12	0·053	3·43	0·015
13	0·039	2·05	0·019
14	0·041	2·54	0·016
Hoshiarpur.			
15	0·053	3·24	0·016
16	0·055	..	..
Gurdaspur.			
17	0·075	2·47	0·030
18	0·058	5·02	0·012
19	0·033	2·85	0·012
20	0·047	5·11	0·009
21	0·032	2·13	0·015
22	0·048	3·12	0·015
23	0·045	1·18	0·038
24	0·046	2·46	0·019
25	0·049	2·05	0·024
26	0·046	1·08	0·043
27	0·048	..	..
28	0·063	..	..
29	0·058	2·4	0·024
30	0·052	..	..
31	0·078	3·59	0·022
32	0·075	3·05	0·025
33	0·082	1·57	0·03[illegible]
34	0·059	..	..
35	0·078	..	..
36	0·048	..	..
37	0·057	..	..

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	GURDASPUR—*contd.*		
38	0·085	..	..
39	0·070	..	..
40	0·050	..	..
41	0·056	..	..
42	0·055	..	..
43	0·063	..	..
44	0·050	..	..
45	0·062	..	..
46	0·053	..	..
48	0·059	3·21	0·018
50	0·075	2·16	0·035
52	0·033	1·78	0·019
	RAWALPINDI.		
54	0·067	3·63	0·018
56	0·041	2·44	0·017
58	0·059	2·90	0·020
	ATTOCK.		
60	0·053	5·17	0·010
63	0·071	9·94	0·007
66	0·037	5·62	0·007
	ATTOCK—*contd.*		
69	0·093	6·96	0·013
72	0·047	5·86	0·008
75	0·090	9·65	0·009
78	0·069	8·76	0·008
81	0·066	7·31	0·009
84	0·056	7·51	0·008
87	0·087	10·31	0·008
90	0·052	10·06	0·005
	HISSAR.		
91	0·053	4·46	0·012
92	0·039	1·30	0·030
93	0·042	4·10	0·010
94	0·053	6·07	0·009
95	0·039	5·19	0·008
96	0·049	5·15	0·010
97	0·074	3·46	0·021
99	0·081	3·43	0·024
101	0·063	3·27	0·019
103	0·038	2·85	0·013
105	0·048	1·79	0·027

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	HISSAR—*contd.*		
106	0·054	2·49	0·022
107	0·050	2·04	0·025
108	0·042	3·80	0·011
109	0·030	2·65	0·011
	KARNAL.		
110	0·051	1·82	0·028
111	0·047	2·09	0·023
112	0·066	..	..
113	0·024	..	..
114	0·074	..	..
115	0·011	..	..
116	0·080	..	..
117	0·074	..	..
118	0·112	..	..
119	0·061	..	..
121	0·070	3·52	0·020
123	0·088	3·12	0·028
125	0·039	3·66	0·011
	FEROZEPUR.		
126	0·101	6·27	0·016
127	0·053	2·65	0·020
128	0·078	5·86	0·013
130	0·066	6·13	0·011
	JULLUNDUR.		
132	0·046	2·26	0·020
133	0·164	7·23	0·023
	LAHORE.		
134	0·034	4·76	0·007
135	0·044	2·28	0·019
	SHEIKHUPURA.		
136	0·036	4·07	0·009
137	0·042	6·92	0·006
138	0·021	0·51	0·004
139	0·030	0·96	0·003
140	0·033	2·17	0·015
141	0·028	0·54	0·005
142	0·077	4·74	0·016
143	0·064	3·99	0·016

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Pecentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	SHEIKHUPURA—*contd.*		
144	0·023	(?)0·10	..
145	0·043	3·01	0·014
146	0·060	2·46	0·024
147	0·031	0·92	0·003
148	0·097	2·25	0·043
149	0·090	2·85	0·032
	UJRAT.		
150	0·073	6·35	0·012
151	0·070	5·61	0·013
152	0·082	4·20	0·020
	MONTGOMERY.		
154	0·024	2·42	0·010
155	0·044	2·99	0·014
156	0·024	..	..
157	0·037	..	..
158	0·027	1·78	0·015
159	0·033	1·52	0·022
160	0·054	2·66	0·020
161	0·034	1·22	0·028
162	0·048	2·53	0·019

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	MONTGOMERY—*contd.*		
163	0·034	1·73	0·020
165	0·038	1·57	0·024
167	0·028	1·68	0·017
169	0·040	2·42	0·017
171	0·038	1·58	0·024
	LYALLPUR.		
173	0·041	1·82	0·023
174	0·043	..	..
175	0·038	..	..
176	0·038	..	..
177	0·052	..	.
178	0·047	..	
179	0·038	..	
180	0·026	..	..
181	0·049	..	..
182	0·042	3·04	0·014
184	0·029	1·24	0·023
	SHAHPUR.		
186	0·033	6·57	0·005
187	0·037	3·13	0·012

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition	Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	SHAHPUR—*contd.*				MULTAN.		
188	0·042	5·00	0·008	216	0·053	3·67	0·011
189	0·014	..	..	217	0·064	7·65	·008
197	0·076	5·60	0·014	218	0·114	..	..
199	0·085	5·45	0·016	219	0·127	..	..
201	0·053	3·40	0·016	220	0·131	..	..
203	0·043	4·01	0·011	221	0·139	..	..
205	0·051	4·56	0·011	228	..	3·88	..
206	0·055	4·74	0·012	229	..	3·51	..
208	0·045	7·00	0·006		MUZAFFARGARH.		
210	0·060	3·39	0·018	230	0·043	..	..
212	0·040	5·89	0·007	231	0·045	6·83	0·066
	JHANG.				DERA GHAZI KHAN.		
214	0·053	3·45	0·015	232	0·026	5·78	0·004
215	0·047	5·46	0·009	233	0·040	3·81	0·011

TABLE V.

The Punjab Soils.

AVERAGE LIME CONTENT AND LIME MAGNESIA RATIO FOR DIFFERENT DISTRICTS OF THE PUNJAB.

District	Lime	Lime/Magnesia
Kangra	0·106	0·366
Amballa	9·98	0·91
Hoshiarpur	1·567	1·505
Gurdaspur	0·453	0·408
Rawalpindi	10·16	6·22
Attock	7·82	5·37
Hissar	1·377	1·069
Karnal	0·916	0·794
Ferozepur	1·47	2·464
Lahore	1·10	0·896
Sheikhupura	1·418	1·059
Gujrat	1·092	0·931
Montgomery	1·40	2·32
Lyallpur	3·32	3·11
Shahpur	3·63	2·16
Jhang	4·28	4·07
Multan	3·29	2·33
Muzaffargarh	5·55	2·82
Dera Ghazi Khan	8·01	4·68

Table VI.

The Punjab Soils.

Potash : Clay, and Aluminia : Clay Ratios.

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
SURFACE SOILS.					
Kangra.					
1	0·714	..	5·8	0·123	..
2	0·687	..	12·10	0·057	..
3	0·728	..	33·60	0·002	..
4	0·683	..	35·05	0·019	..
5	0·713	..	36·21	0·020	..
6	0·423	..	19·00	0·023	..
7	0·414	..	11·72	0·035	..
Ambala.					
8	0·411	..	4·80	0·085	..
9	0·974	..	19·60	0·050	..
10	0·220	2·50	6·72	0·033	·37
11	0·270	2·41	6·08	0·044	·40
12	0·290	3·07	9·92	0·029	·31
13	0·460	3·57	7·44	0·062	·48
14	0·480	3·73	10·56	0·045	·35
Hoshiarpur.					
15	0·599	..	8·32	0·072	..
16	0·418	..	7·04	0·059	..
Gurdaspur.					
17	0·688	..	4·09	0·168	..
18	0·638	..	4·62	0·138	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		GURDASPUR—*contd.*			
19	0·744	..	9·28	0·080	..
20	0·831	..	11·20	0·074	..
21	0·688	..	9·12	0·075	..
22	0·366	..	6·40	0·057	..
23	0·343	..	5·92	0·058	..
24	0·381	.	6·40	0·060	..
25	0·448	..	6·40	0·070	..
26	0·422	..	6·32	0·067	..
27	0·443	..	7·36	0·060	..
28	0·351	..	10·23	0·031	..
29	0·304	..	15·60	0·019	..
30	0·292		12·48	0·023	..
31	0·314	..	12·96	0·024	..
32	0·336	..	9·28	0·036	..
33	0·317	..	7·36	0·043	..
34	0·910	..	..	..	..
35	1·250	.	..	..	..
36	1·030	..	..	..	..
37	0·940	..	..	..	..
38	1·700	..	..	..	..
39	1·380	..	..	..	..
40	0·880	..	..	..	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		GURDASPUR—*contd.*			
41	0·720	..	..	..	..
42	0·870	..	..	..	..
43	0·910	..	..	..	..
44	0·990	..	..	..	..
45	1·220	..	..	..	..
46	1·260	..	..	..	..
47	..	..	6·24	..	..
48	0·520	4·68	14·80	0·035	0·32
50	0·430	3·47	6·83	0·063	0·58
52	0·430	3·56	7·28	0·059	0·49
		RAWALPINDI.			
54	0·700	5·92	13·92	0·050	0·43
56	0·496	5·91	22·08	0·023	0·27
58	0·302	5·86	8·64	0·035	0·68
		ATTOCK.			
59	0·765	7·13	21·56	0·036	0·331
63	0·552	6·31	27·28	0·020	0·231
66	0·424	6·78	21·62	0·020	0·313
69	0·202	7·73	20·58	0·010	0·376
72	0·524	6·01	14·28	0·037	0·421
73	0·677	5·67	21·44	0·032	0·265

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		ATTOCK—*contd.*			
78	0·632	9·29	16·80	0·038	0·553
81	0·517	7·31	19·20	0·027	0·381
84	0·872	6·98	20·28	0·043	0·344
87	0·764	7·86	14·50	0·053	0·542
90	0·761	8·80	19·20	0·040	0·458
		HISSAR.			
91	1·680	..	15·52	0·108	..
92	0·495	..	13·44	0·037	..
93	0·646	..	12·80	0·050	..
94	0·717	..	14·72	0·050	..
95	0·710	..	11·20	0·063	..
96	1·297	..	33·44	0·039	..
97	0·682	4·58	16·48	0·041	0·278
99	0·666	6·74	18·40	0·036	0·366
101	0·736	6·99	26·08	0·028	0·268
103	0·572	1·36 (?)	14·24	0·040	0·096
105	0·910	4·71	15·30	0·059	0·308
106	1·010	5·88	13·28	0·076	0·442
107	0·940	5·50	15·84	0·059	0·347
108	0·640	5·59	15·66	0·041	0·357
109	0·790	4·85	16·60	0·048	0·292

Table VI—*contd.*

The Punjab Soils—contd.

Potash : Clay, and Aluminia : Clay Ratios—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		Karnal.			
110	0·873	..	14·72	0·059	..
111	0·883	..	16·16	0·055	..
		Hissar.			
119	0·650	4·86	9·44	0·069	0·516
121	0·670	5·02	16·96	0·040	0·296
123	1·100	6·57	9·44	0·117	0·696
125	0·640	3·98	7·62	0·085	0·529
		Ferozepur.			
126	1·090	..	14·56	0·075	..
127	0·867	..	14·74	0·059	..
128	0·775	5·83	13·60	0·057	0·429
130	0·721	5·49	13·92	0·052	0·394
		Jullundur.			
132	0·786	..	6·90	0·114	..
133	1·459	..	28·08	0·052	..
		Lahore.			
134	0·790	..	12·48	0·063	..
135	0·930	..	15·04	0·062	..

Table VI—*contd.*

The Punjab Soils—contd.

Potash : Clay and Alumina : Clay Ratios—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Alumina Al_2O_3	Clay	Potash : Clay	Alumina : Clay
		SURFACE SOILS—*contd.*			
		Sheikhupura.			
136	0·710	..	16·96	0·042	..
137	0·290	..	7·52	0·039	..
138	0·205	2·26	..	..	..
139	0·165	3·98	..	..	..
140	0·888	5·72			..
141	0·329	3·05	..	..	..
142	0·825	6·44		..	..
143	1·142	2·18			..
144	0·196	2·81	..	..	..
145	0·791	5·74	..	..	..
146	0·330	6·30	..	..	..
147	0·636	3·44	..	..	..
148	0·727	5·43	..	..	..
149	0·899	7·36		..	..
		Gujrat.			
150	0·760	..	14·08	0·054	..
151	0·372	..	4·64	0·080	..
152	0·702	..	13·44	0·052	..
		Montgomery.			
153	..	..	17·50	..	..
156	0·780	..	10·88	0·072	..

Table VI—*contd.*

The Punjab Soils—contd.

Potash : Clay, and Aluminia : Clay Ratios—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		Montgomery—*contd*			
157	0·950	..	..	..	..
158	0·810	5·20	12·40	0·065	0·41
159	0·720	5·27	11·40	0·063	0·40
160	0·630	4·54	11·44	0·055	0·40
161	0·760	4·47	11·54	0·066	0·39
162	0·780	4·97	12·43	0·063	0·40
163	0·900	4·83	11·72	0·077	0·41
165	1·040	5·55	14·59	0·071	0·38
167	0·770	4·66	12·78	0·060	0·36
169	0·840	4·29	11·65	0·072	0·37
171	0·990	5·21	18·72	0·053	0·29
		Lyallpur.			
173	0·827	..	10·95	0·075	..
174	1·250	..	..	..	..
175	1·300	..	..	..	..
176	1·030	..	..	..	..
177	1·190	..	..	..	..
178	1·200	..	..	..	..
179	0·960	..	..	..	..
180	0·780	..	..	..	..
181	0·760	..	..	..	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
			SURFACE SOILS—*contd.*		
			LYALLPUR—*contd.*		
182	0·500	5·28	15·60	0·032	0·34
184	0·550	4·40	10·11	0·051	0·43
			SHAHPUR.		
186	0·956	..	7·01	0·014	..
187	0·743	..	13·92	0·053	..
188	..	..	12·64	..	..
			SHAHPUR (MONA).		
197	0·881	10·19	21·12	0·042	0·51
199	0·549	8·53	28·61	0·020	0·30
201	0·397	4·68	10·72	0·037	0·44
203	1·079	7·96	23·69	0·046	0·34
205	1·020	8·25	22·08	0·046	0·37
			SHAHPUR (SARGODHA).		
206	0·693	6·86	15·84	0·044	0·43
208	0·724	7·24	20·96	0·035	0·35
210	0·547	5·13	8·00	0·068	0·64
212	0·689	6·10	16·00	0·043	0·38
			JHANG.		
214	0·847	..	5·58	0·015	..
215	0·837	..	4·90	0·017	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		MULTAN.			
228	0·675	5·99	..	..	..
229	0·808	6·14	..	..	..
		MUZAFFARGARH			
230	0·861	..	20·32	0·042	..
231	0·822	..	13·28	0·062	..
		DERA GHAZI KHAN.			
232	0·687	..	9·28	0·074	..
233	0·802	..	16·18	0·049	..
		SUB-SOILS			
		GURDASPUR.			
49	0·57	5·33	21·36	0·026	0·25
51	0·53	4·35	19·01	0·028	0·23
53	0·44	3·77	11·70	0·038	0·32
		RAWALPINDI.			
55	0·59	5·38	14·08	0·042	0·38
57	0·51	3·48	22·24	0·023	0·16
59	0·47	3·92	6·72	0·070	0·58

Table VI—*contd.*

The Punjab Soils—contd.

Potash - Clay, and Aluminia : Clay Ratios *contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
			SUB SOILS—*contd.*		
			Attock (2nd foot).		
61	0·88	8·86	23·00	0·038	0·38
64	0·46	5·84	32·40	0·014	0·18
67	0·41	5·68	20·98	0·019	0·27
70	0·62	9·37	21·12	0·029	0·44
73	0·51	7·83	17·63	0·031	0·44
76	0·72	8·96	25·80	0·028	0·35
79	0·49	9·42	19·20	0·025	0·49
82	0·80	7·06	19·04	0·042	0·37
85	·84	7·16	17·86	0·047	0·40
88	0·81	8·65	16·09	0·050	0·55
			Attock (3rd foot).		
62	0·73	6·11	27·25	0·027	0·22
65	0·78	7·89	39·52	0·020	0·20
68	0·40	6·64	19·35	0·021	0·34
71	0·60	7·67	20·56	0·029	0·37
74	0·64	7·67	22·36	0·029	0·34
77	0·52	7·69	25·20	0·021	0·31
80	0·49	7·06	17·62	0·028	0·40
83	0·65	7·22	16·96	0·038	0·43
86	1·06	7·88	19·20	0·055	0·41
89	0·75	8·52	15·00	0·05	0·56

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SUB-SOILS—*contd.*			
		HISSAR.			
98	0·63	5·96	21·76	0·029	0·27
100	0·59	6·10	21·28	0·028	0·29
102	0·77	8·00	36·64	0·021	0·22
104	0·38	3·29	15·52	0·024	0·21
		KARNAL.			
120	0·65	4·75	16·64	0·039	0·28
122	0·91	7·31	12·96	0·070	0·56
124	0·88	7·31	14·88	0·059	0·49
		FEROZEPUR.			
129	0·79	5·98	13·76	0·057	0·44
131	0·76	5·97	15·52	0·049	0·38
		JULLUNDUR.			
132	0·79	..	6·90	0·011	..
133	1·50	..	28·08	0·053	..
		MONTGOMERY.			
164	0·85	5·19	13·48	0·063	0·38
166	1·05	5·79	15·87	0·066	0·37
168	0·80	4·53	14·72	0·054	0·31

TABLE VI—*concld.*

The Punjab Soils—concld.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Serial No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
			SUB-SOILS—*contd.*		
			MONTGOMERY—*contd.*		
170	0·77	4·74	10·24	·075	0·46
172	1·12	5·54	18·05	0·062	0·31
			LYALLPUR.		
183	·60	5·57	14·40	·042	·39
185	·60	4·30	10·64	·056	·40
			SHAHPUR (MONA).		
198	·956	8·59	25·60	·037	·34
200	·901	8·53	32·32	·028	·26
202	·34	4·10	9·44	·036	·43
204	·90	8·76	23·84	·038	·37
			SHAHPUR (SARGODHA).		
207	·89	6·88	15·36	·058	·45
209	1·06	8·27	26·40	·040	·31
211	·50	5·10	8·48	·059	·60
213	·59	5·63	16·96	·035	·33

TABLE VII.

The Punjab Soils.

PHOSPHORIC ACID.

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent
1	Kangra . . .	0·34	26	Gurdaspur . . .	0·62
2	,, . . .	0·79	27	,, . . .	0·82
3	,, . . .	0·39	28	,, . . .	0·45
4	,, . . .	0·47	29	,, . . .	0·44
5	,, . . .	0·34	30	,, . . .	0·49
6	,, . . .	0·30	31	,, . . .	0·41
7	,, . . .	0·22	32	,, . . .	0·44
8	Amballa . . .	0·16	33	,, . . .	0·33
9	,, . . .	0·21	34	,, . . .	0·12
10	,, . . .	0·14	35	,, . . .	0·16
11	,, . . .	0·11	36	,, . . .	0·14
12	,, . . .	0·24	37	,, . . .	0·07
13	,, . . .	0·18	38	,, . . .	0·18
14	,, . . .	0·15	39	,, . . .	0·10
15	Hoshiarpur . . .	0·46	40	,, . . .	0·05
16	,, . . .	0·13	41	,, . . .	0·06
17	Gurdaspur . . .	0·16	42	,, . . .	0·06
18	,, . . .	0·18	43	,, . . .	0·07
19	,, . . .	0·11	44	,, . . .	0·18
20	,, . . .	0·11	45	,, . . .	0·07
21	,, . . .	0·06	46	,, . . .	0·05
22	,, . . .	0·71	48	,, . . .	0·10
23	,, . . .	0·65	50	,, . . .	0·08
24	,, . . .	0·56	52	,, . . .	0·16
25	,, . . .	0·64	54	Rawalpindi . . .	0·20

Table VII—*contd.*

The Punjab Soils—contd.

Phosphoric Acid—*contd.*

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent.
55	Rawalpindi . . .	0·21	107	Hissar . . .	0·15
58	„ . . .	0·16	108	„ . . .	0·13
60	Attock : . .	0·17	109	„ . . .	0·13
63	„ . . .	0·10	110	Karnal . . .	0·36
66	„ . . .	0·17	111	„ . . .	0·39
69	„ . . .	0·10	119	„ . . .	0·13
72	„ . . .	0·10	121	„ . . .	0·12
75	„ . . .	0·37	123	„ . . .	0·14
78	„ . . .	0·26	125	„ . . .	0·13
81	„ . . .	0·20	126	Ferozepur . . .	0·24
84	„ . . .	0·12	127	„ . . .	0·29
87	„ . . .	0·04	128	„ . . .	0·21
90	„ . . .	0·02	130	„ . . .	0·23
91	Hissar . . .	0·11	132	Jullundur . . .	0·21
92	„ . . .	0·11	133	„ . . .	0·16
93	„ . . .	0·16	134	Lahore . . .	0·13
94	„ . . .	0·14	135	„ . . .	0·10
95	„ . . .	0·14	136	Sheikhupura . .	0·13
96	„ . . .	0·12	137	„ . . .	0·11
97	„ . . .	0·32	138	„ . . .	0·16
99	„ . . .	0·24	139	„ . . .	0·15
101	„ . . .	0·19	140	„ . . .	0·09
103	„ . . .	0·22	141	„ . . .	0·13
105	„ . . .	0·15	142	„ . . .	0·20
106	„ . . .	0·32	143	„ . . .	0·25

TABLE VII—*contd.*

The Punj Soils—contd.

PHOSPHORIC ACID—*contd.*

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent.
144	Sheikhupura . .	0·14	177	Lyallpur . . .	0·20
145	„ . . .	0·08	178	„ . . .	0·18
146	„ . . .	0·12	179	„ . . .	0·14
147	„ . . .	0·12	180	„ . . .	0·14
148	„ . . .	0·20	181	„ . . .	0·14
149	„ . . .	0·15	182	„ . . .	0·23
150	Gujrat . . .	0·23	184	„ . . .	0·22
151	„ . . .	0·16	186	Shahpur . . .	0·22
152	„ . . .	0·29	187	„ . . .	1·60 ?
156	Montgomery . .	0·15	188	„ . . .	0·28
157	„ . . .	0·29	197	Shahpur Mona . .	0·15
158	„ . . .	0·19	199	„ „ . .	0·17
159	„ . . .	0·21	201	„ „ . .	0·15
160	„ . . .	0·23	203	„ „ . .	0·23
161	„ . . .	0·21	205	„ „ . .	0·24
162	„ . . .	0·19	206	Shahpur Sargodha .	0·23
163	„ . . .	0·21	208	„ „ .	0·26
165	„ . . .	0·20	210	„ „ .	0·18
167	„ . . .	0·21	212	„ „ .	0·16
169	„ . . .	0·18	214	Jhang	0·64
171	„ . . .	0·21	215	„	0·63
173	Lyallpur . . .	0·35	216	Multan . . .	0·53
174	„ . . .	0·21	217	„ . . .	0·24
175	„ . . .	0·16	228	„ . . .	0·17
176	„ . . .	0·15	229	„ . . .	0·16

TABLE VII—*contd.*

The Punjab Soils—contd.

PHOSPHORIC ACID—*contd.*

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent.
230	Muzaffargarh . .	0·20	232	Dera Ghazi Khan . .	0·67
231	„ . .	0·22	233	„ . .	1·36 ?

TABLE VIII.

The Punjab Soils.

IRON AND ALUMINIUM.

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
		SURFACE SOILS.			
	AMBALLA.			ATTOCK.	
10	3·21	2·50	60	4·32	7·13
11	3·29	2·44	63	4·21	6·31
12	3·68	3·07	66	4·93	6·75
13	2·34	3·57	69	5·99	7·73
14	2·95	3·73	72	4·72	6·01
			75	4·08	5·67
	GURDASPUR.		78	3·58	9·29
48	4·24	4·68	81	5·58	7·31
50	3·16	3·47	84	4·86	6·98
52	3·08	3·56	87	4·96	7·86
			90	5·94	8·80
	RAWALPINDI.			HISSAR.	
54	5·09	5·92			
56	3·66	5·91	97	3·28	4·58
58	4·52	5·86	99	1·10	6·74

TABLE VIII—*contd.*

The Punjab Soils—contd.

IRON AND ALUMINIUM—*contd.*

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
		SURFACE SOILS—*contd.*			
	HISSAR—*contd.*			SHEIKHUPURA—*contd.*	
101	4·96	6·99	144	1·28	2·81
105	4·04	4·71	145	3·26	5·74
106	3·84	5·88	146	4·10	6·30
107	4·08	5·50	147	1·94	3·41
108	3·80	5·59	148	4·42	5·43
109	3·68	4·85	149	3·82	7·36
	KARNAL.			MONTGOMERY.	
119	4·08	4·86	158	3·60	5·20
121	4·08	5·02	159	3·20	5·27
123	3·47	6·57	160	4·00	4·54
125	3·04	3·98	161	3·76	4·47
	FEROZEPUR.		162	3·96	4·97
128	4·24	5·83	163	4·20	4·83
130	4·12	5·49	165	4·40	5·55
	SHEIKHUPURA.		167	4·12	4·66
138	1·98	2·26	169	4·04	4·29
139	1·78	3·98	171	4·60	5·21
140	3·26	5·72			
141	1·86	3·05		LYALLPUR.	
142	4·33	6·11	182	2·38	5·28
143	4·44	2·18	184	2·63	4·40

TABLE VIII—*contd.*

The Punjab Soils—contd.

IRON AND ALUMINIUM—*contd.*

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
		SURFACE SOILS—*contd.*			
	SHAHPUR (MONA).			SHAHPUR (SARGODHA)—*contd.*	
197	2·64	10·19	210	3·76	5·13
199	4·72	8·53	212	5·05	6·10
201	3·44	4·68			
203	5·38	7·96			
205	3·89	8·25			
	SHAHPUR (SARGODHA).			MULTAN.	
206	4·44	6·86	228	4·46	5·99
208	4·85	7·24	229	4·92	6·14
		SUB-SOILS.			
	GURDASPUR.			ATTOCK (II ft.)—*contd.*	
49	4·60	5·33	67	4·32	5·68
51	3·53	4·35	70	6·00	9·37
53	3·38	3·77	73	5·20	7·83
			76	3·36	8·96
	RAWALPINDI.		79	3·20	9·42
55	4·93	5·38	82	5·20	7·06
57	3·40	3·48	85	4·92	7·16
59	4·48	3·92	88	5·71	8·65
	ATTOCK (II ft.).			ATTOCK (III FT.).	
61	4·50	8·86	62	4·31	6·11
64	4·30	5·84	65	4·22	7·89

Table VIII—*contd.*

The Punjab Soils—contd.

Iron and Aluminium—*contd.*

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
		SUB-SOILS—*contd.*			
	Attock (III ft.)—*contd.*			Montgomery.	
68	5·60	6·64	164	4·28	5·19
71	5·48	7·67	166	4·44	5·79
74	6·08	7·67	168	4·40	4·53
77	3·41	7·69	170	4·10	4·74
80	3·69	7·06	172	4·64	5·54
83	5·36	7·22			
86	5·40	7·88		Lyallpur.	
89	5·88	8·52	183	2·52	2·27
	Hissar.		185	5·57	4·30
98	3·56	5·96			
100	4·20	6·10		Shahpur (Mona).	
102	5·12	8·00	198	5·68	8·59
104	5·60	3·29	200	5·72	8·53
			202	3·64	4·10
	Karnal.		204	5·77	8·76
120	4·20	4·75			
122	3·42	7·31			
124	3·47	7·31		Shahpur (Sargodha).	
			207	4·90	6·88
	Ferozepur.		209	5·72	8·27
129	4·32	5·98	211	3·79	5·10
131	4·69	5·97	213	4·88	5·63

TABLE IX.

The Punjab Soils.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA.

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS.			
			AMBALA.			
10	90·33	2·50	2·73	36·10	1	1·1
11	90·88	2·44	2·81	37·21	1	1·2
12	87·52	3·07	2·52	28·51	1	0·8
13	90·63	3·57	2·65	25·38	1	0·7
14	89·43	3·73	2·83	23·98	1	0·7
			AVERAGE .	30·24	1	·9
			GURDASPUR.			
48	88·32	4·68	2·44	18·87	1	0·5
50	88·31	3·47	2·89	25·45	1	0·8
52	91·95	3·56	3·12	25·83	1	0·9
			AVERAGE .	23·38	1	·7
			RAWALPINDI.			
54	67·61	5·95	14·29	11·37	1	2·4
56	64·74	5·91	14·33	10·95	1	2·4
58	72·80	5·86	1·00	13·00	1	2·0
			AVERAGE .	11·77	1	2·3

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS—*contd.*			
			HISSAR.			
97	85·02	4·58	4·31	18·56	1	0·9
99	88·57	6·71	4·81	12·70	1	0·7
101	84·83	6·99	3·85	12·13	1	0·56
105	85·33	4·71	2·72	18·75	1	0·6
106	85·06	5·88	3·03	14·47	1	0·5
107	84·97	5·50	2·80	15·45	1	0·5
108	86·30	5·59	2·08	15·44	1	0·3
109	87·43	4·85	3·02	18·03	1	0·4
			AVERAGE .	15·70	1	·56
			KARNAL.			
119	87·17	4·86	3·17	17·94	1	·66
121	86·65	5·02	2·94	17·26	1	·58
123	83·92	6·57	3·55	12·77	1	·50
125	88·79	3·98	2·31	22·31	1	·6
			AVERAGE .	17·57	1	·58
			FEROZEPUR.			
128	76·76	5·83	7·84	13·17	1	1·3
130	77·22	5·49	8·07	14·06	1	1·5
			AVERAGE .	13·61	1	1·4

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS—*contd.*			
			MONTGOMERY.			
158	81·86	5·2	8·14	15·74	1	1·5
159	83·56	5·27	7·92	15·85	1	1·5
160	86·38	4·54	6·35	19·02	1	1·4
161	82·23	4·47	8·90	18·40	1	2·0
162	84·03	4·97	7·92	16·91	1	1·6
163	81·31	4·83	5·95	16·83	1	1·2
165	79·16	5·55	6·40	14·25	1	1·1
167	82·91	4·66	5·80	17·79	1	1·2
169	81·19	4·29	7·01	18·93	1	1·6
171	78·05	5·21	7·37	14·98	1	1·4
			AVERAGE .	16·87	1	1·45
			LYALLPUR.			
182	81·84	5·28	6·68	15·50	1	1·2
184	88·10	4·40	3·36	22·02	1	0·7
			AVERAGE .	18·76	1	·95

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS—*concld.*			
			SHAHPUR.			
197	78·61	10·19	5·53	7·71	1	·54
199	75·92	8·53	3·09	8·90	1	·36
201	79·64	4·68	8·19	17·01	1	1·75
203	78·03	7·96	4·64	9·80	1	·58
205	79·30	8·25	5·48	9·61	1	·66
207	76·90	6·86	5·92	11·21	1	·86
209	81·52	8·27	6·21	9·86	1	·75
211	70·84	5·10	10·27	13·89	1	2·01
213	77·44	5·63	5·25	13·75	1	·93
			AVERAGE .	11·30	1	·94
			SUB-SOILS.			
			GURDASPUR.			
49	87·14	5·33	2·33	16·35	1	0·4
51	88·54	3·47	2·89	20·36	1	0·7
53	90·03	3·77	1·73	23·88	1	0·5
			AVERAGE .	20·20	1	·53

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SUB-SOILS—*contd.*			
			RAWALPINDI.			
55	65·76	5·38	12·70	12·22	1	2·36
57	63·39	3·48	14·69	18·22	1	4·2
59	71·68	3·92	11·78	18·28	1	3·0
			AVERAGE .	16·57	1	3·19
			HISSAR.			
98	82·42	5·96	4·65	13·83	1	0·9
100	84·73	6·10	5·16	13·89	1	0·8
102	84·53	8·00	3·56	10·57	1	0·44
104	86·34	3·29	2·57	26·24	1	0·80
			AVERAGE .	16·13	1	·72
			KARNAL.			
120	85·71	4·75	2·98	18·04	1	0·60
122	81·78	7·31	3·27	11·19	1	0·40
124	88·79	3·98	2·31	11·41	1	·40
			AVERAGE .	13·55	1	·50
			FEROZEPUR.			
129	75·07	5·98	8·40	12·55	1	1·4
131	74·31	5·97	8·76	12·41	1	1·5
			AVERAGE .	12·49	1	1·5

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soils.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SUB-SOILS—*concld.*			
			MONTGOMERY.			
164	81·34	5·19	6·48	15·67	1	1·2
166	76·09	5·79	7·94	13·14	1	1·3
168	81·11	4·53	6·80	17·91	1	1·5
170	79·26	4·74	8·40	16·72	1	1·8
172	77·56	5·51	7·99	14·00	1	1·4
			AVERAGE .	15·49	1	1·4
			LYALLPUR.			
183	78·49	5·57	6·99	14·09	1	1·2
185	86·79	4·30	4·09	20·18	1	0·9
			AVERAGE .	17·14	1	1·1
			SHAHPUR.			
198	62·29	8·59	4·98	7·25	1	·58
200	75·21	8·53	4·52	8·82	1	·53
202	75·39	4·10	6·55	18·39	1	1·60
204	76·51	8·76	4·25	8·73	1	·48
206	77·49	6·86	6·38	12·15	1	·93
208	76·05	7·24	12·79	10·51	1	1·77
210	78·95	5·13	7·44	15·39	1	1·45
212	68·25	6·10	12·39	11·19	1	2·03
			AVERAGE .	11·55	1	1·17

TABLE X.

The Punjab Soils.

ANALYSES OF WHEAT SOILS.

LOCALITY	AMBALLA		HOSHIAR-PUR	GURDAS-PUR	RAWALPINDI		HISSAR		
DESCRIPTION	S. L. 1	L. 1	S. L. 2	L. 4	L. 1	C. L. 2	C. L. 1	S. L. 2	L. 3
Number	8	10	15	20	54	56	93	95	106
Mechanical.									
Fine Gravel	*Nil*	*Nil*	0·68	0·71	0·53	0·14	0·43	0·12	0·22
Coarse sand	·89	2·96	21·02	7·46	2·37	1·02	·60	4·46	2·02
Fine sand	71·79	50·82	41·46	31·64	26·86	19·38	62·38	59·12	53·50
Silt	13·07	24·63	14·40	23·40	32·15	25·96	10·11	11·59	16·20
Fine silt	7·36	11·36	10·88	20·48	17·92	24·80	9·28	8·32	14·45
Clay	4·89	6·72	8·32	11·20	13·92	22·08	12·80	11·20	13·28
Chemical.									
Potash as K_2O	0·41	0·22	0·60	0·83	0·70	0·59	0·65	0·71	1·01
Phosphoric acid P_2O_5	0·16	0·14	0·46	0·11	0·20	0·21	0·16	0·14	0·32
Lime as CaO	1·19	0·93	2·51	0·84	11·44	11·20	2·04	1·05	1·23
Magnesia as MgO	0·85	1·15	1·1	1·63	1·75	2·17	1·07	1·37	0·69
Iron and Aluminium (Fe_2O_3 + Al_2O_3).	6·91	3·21 *plus* 2·50	6·71	10·70	5·09 *plus* 5·92	3·66 *plus* 5·91	8·42	8·73	3·84 *plus* 5·88
Potash (Available)	..	..	..	..	..	..	..	..	..
Phosphoric (Available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·02	0·06	0·05	0·047	0·07	0·04	0·04	0·04	0·05

TABLE X—*contd.*

The Punjab Soils—contd.

ANALYSES OF WHEAT SOILS—*contd.*

LOCALITY	KARNAL			FEROZEPUR		JULLUNDUR	LAHORE	SHEIKHUPURA	
DESCRIPTION	C. L. 1	L. 4	L. 3	L. 5	L. 4	C	L. 4	L. 3	L. 3
Number	110	121	125	126	128	133	135	136	137
Mechanical.									
Fine Gravel	*Nil*	0·05	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	0·39	0·52
Coarse sand	9·84	1·74	21·0	9·90	3·82	1·82	2·01	15·74	23·20
Fine sand	40·32	47·29	36·62	26·84	40·47	6·22	45·63	36·73	36·24
Silt	15·38	18·67	25·18	26·67	20·30	17·56	22·88	16·18	17·53
Fine silt	17·92	16·96	7·52	17·75	15·76	38·28	12·16	9·92	8·00
Clay	14·72	16·96	7·52	14·56	13·60	38·08	15·04	16·96	7·52
Chemical.									
Potash as K_2O	0·87	0·67	0·64	1·09	0·78	1·46	0·93	0·71	0·29
Phosphoric acid P_2O_5	0·36	0·12	0·13	0·24	0·21	0·16	0·10	0·13	0·11
Lime as CaO	2·17	0·43	1·09	4·13	4·71	..	1·24	1·33	3·25
Magnesia as MgO	1·29	1·34	0·46	2·65	1·94	..	1·19	0·93	1·94
Iron and Aluminium (Fe_2O_3 + Al_2O_3.)	8·74	4·08 *plus* 5·02	3·04 *plus* 3·98	11·12	4·24 *plus* 5·83	..	11·52	11·02	5·74
Potash (Available)	..	..	..	..	..	..	..	..	..
Phosphoric (Available)	..	..	..	..	..	..	..	..	..
NITROGEN (o/o on air dried soil)	0·05	0·07	0·04	0·10	0·08	0·16	0·04	0·04	0·04

TABLE X—*concld.*

The Punjab Soils—concld.

ANALYSES OF WHEAT SOILS—*concld.*

LOCALITY	MONTGOMERY	LYALLPUR	SHAHPUR	JHANG	MUZAFFARGARH	DERA GHAZI KHAN	MULTAN
DESCRIPTION	L. 3	L. 3	S. L. 2	St.	C.	S. L. 2	St.
Number	162	173	186	214	231	233	216
Mechanical.							
Fine Gravel	1·00	0·34	0·06	*Nil*	*Nil*	*Nil*	*Nil*
Coarse sand	2·54	8·24	17·63	9·44	4·08	40·82	7·36
Fine sand	46·43	41·32	45·07	12·00	41·47	18·72	14·92
Silt	20·63	18·63	15·63	20·80	22·02	9·93	22·58
Fine silt	13·85	18·70	8·00	48·73	12·32	10·24	47·69
Clay	12·43	10·95	7·04	5·58	13·28	16·48	3·78
Chemical.							
Potash as K_2O	0·78	0·83	0·96	0·85	0·82	0·80	0·85
Phosphoric acid P_2O_5	0·19	0·35	0·22	0·64	0·22	1·36	0·64
Lime as CaO	5·05	6·28	3·42	4·40	6·02	6·03	4·40
Magnesia as MgO	1·94	0·89	1·86	1·60	1·99	1·73	1·60
Iron and Aluminium (Fe_2O_3 + Al_2O_3)	3·96 *plus* 4·97	9·99	9·90	8·45	10·74	8·30	8·45
Potash (Available)	..	..	..	..	..	..	..
Phosphoric (Available)	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·05	0·04	0·03	0·05	0·05	0·04	0·05

TABLE XI.

The Punjab Soils.

ANALYSES OF COTTON SOILS.

LOCALITY	GURDASPUR	HISSAR			MONTGOMERY	LYALLPUR	SHAHPUR	JHANG	MULTAN	LAHORE
DESCRIPTION	L. 3	S. L. 2	C. L. 1	L. 3	L. 3	L. 3	L. 3	St.	H. St. L.	
Number	30	92	93	94	162	173	187	214	217	135
Mechanical.										
Fine Gravel	0·41	*Nil*	0·43	0·08	1·00	0·34	*Nil*	*Nil*	0·12	*Nil*
Coarse sand	23·87	1·30	0·60	0·46	2·54	8·24	10·89	9·44	1·10	2·01
Fine sand	32·30	65·55	62·38	59·12	46·43	41·32	44·32	12·00	14·22	45·63
Silt	17·92	9·29	10·11	11·59	20·63	18·63	13·50	20·80	31·79	22·88
Fine silt	12·99	9·12	9·28	8·32	13·85	18·70	14·24	48·73	30·40	12·16
Clay	12·48	13·44	12·80	11·20	12·43	10·95	13·92	5·58	14·72	15·04
Chemical.										
Potash as K_2O	0·29	0·50	0·65	0·72	0·78	0·83	0·74	0·85	0·72	0·93
Phosphoric acid as P_2O_5.	0·49	0·11	0·16	0·14	0·19	0·35	1·61	0·64	0·24	0·10
Lime as CaO	0·27	0·99	2·04	0·92	5·05	6·28	3·45	4·40	3·06	1·24
Magnesia as MgO	0·82	0·86	1·07	0·87	1·94	0·89	1·29	1·60	1·23	1·29
Iron and Aluminium ($Fe_2O_3 + Al_2O_3$)	6·87	8·12	8·42	8·75	3·96 *plus* 4·97	9·99	8·02	8·45	10·73	11·52
Potash (Available)	0·03	..	..	..	..	..	..	..	..	..
Phosphoric (Available)	0·11	..	..	..	..	..	..	..	..	..
NITROGEN (o/o on air dried soil).	0·052	0·04	0·04	0·05	0·05	0·04	0·037	0·05	0·06	0·04

TABLE XII.

The Punjab Soils.

ANALYSES OF SUGARCANE SOILS.

LOCALITY	HOSHIARPUR	GURDASPUR				HISSAR	KARNAL	LAHORE	SHEIKHUPURA	GUJRAT	MONTGOMERY	SHAHPUR
DESCRIPTION	S. L. 1	S. L. 2	L. 3	L. 5	L. 1	S. L. 2	L. 5	L. 5	L. 3	L. 5	L. 3	L. 3
Number	16	19	28	29	33	103	111	135	136	150	162	188
Mechanical.												
Fine Gravel	·03	..	1·14	0·25	0·11	0·07	*Nil*	*Nil*	0·39	*Nil*	1·00	*Nil*
Coarse sand	36·60	35·99	25·96	23·00	23·70	·62	2·38	2·01	15·74	14·79	2·54	13·91
Fine sand	38·54	30·22	28·10	22·91	27·23	60·77	46·05	45·63	36·73	26·83	46·43	39·39
Silt	10·38	11·52	16·10	20·01	25·44	16·85	18·17	22·86	16·18	25·15	20·63	17·86
Fine silt	6·40	10·24	12·71	17·93	12·94	9·28	18·24	12·16	9·92	12·80	13·85	11·20
Clay	7·04	9·28	10·23	15·60	7·36	14·24	16·16	15·04	16·96	14·08	12·43	12·64
Chemical.												
Potash as K_2O	0·42	0·74	0·35	0·30	0·32	0·57	0·88	0·93	0·71	0·76	0·78	..
Phosphoric acid P_2O_5	0·13	0·11	0·45	0·44	0·33	0·22	0·39	0·10	0·13	0·23	0·19	0·28
Lime as CaO	0·63	0·37	0·90	0·28	0·27	1·16	1·28	1·24	1·33	1·23	5·05	3·23
Magnesia as MgO	0·85	1·40	1·03	0·97	0·79	0·53	1·55	1·19	·93	1·60	1·94	1·71
Iron and Aluminium ($Fe_2O_3 + Al_2O_3$.)	5·84	8·71	8·08	9·01	8·07	7·84 + 1·36	8·82	11·52	11·02	10·72	3·97 + 4·97	8·69
Potash (Avl.)	..	..	0·05	0·03	0·02	..	..	..	..	..	..	..
Phosphoric (Avl.)	..	..	0·15	0·08	0·04	..	..	..	..	..	..	..
Nitrogen (o/o on air dried soil).	0·06	0·03	0·06	0·06	0·05	0·04	0·05	0·04	0·04	0·07	0·05	0·04

Table XIII.

The Punjab Soils.

Analyses of Rice Soils.

Locality	Amballa	Gurdaspur		Hissar		Jullundur	Gujrat	Muzaffargarh
Description	H. St. L.	L1	St.	Cl.	C. L. 2	C. L.	L5	C. 12
Number	9	17	18	96	101	133	152	230
Mechanical.								
Fine Gravel	*Nil*	*Nil*	*Nil*	0·26	*Nil*	*Nil*	*Nil*	*Nil*
Coarse sand	·89	14·88	6·08	0·12	1·48	1·82	8·61	4·08
Fine sand	71·79	31·84	15·84	36·40	33·91	6·22	29·64	41·47
Silt	13·07	23·47	28·05	9·75	17·24	17·56	26·19	22·02
Fine silt	7·36	23·25	40·39	14·88	19·36	36·28	17·92	12·32
Clay	4·80	4·09	4·62	33·44	26·08	28·08	13·44	13·28
Chemical.								
Potash as K_2O.	0·41	0·69	0·64	1·30	0·74	1·46	0·70	0·82
Phosphoric acid P_2O_5	0·16	0·16	0·18	0·12	0·19	0·16	0·29	0·22
Lime as CaO	1·19	0·49	0·52	0·89	1·37	..	1·21	6·02
Magnesia as MgO.	·85	2·25	1·95	0·62	1·49	..	1·02	1·99
Iron and Aluminium (Fe_2O_3 Al_2O_3)	6·91	11·92	9·81	15·64	4·96+ 6·99	..	10·24	10·74
Potash (Avl.)	..	..	..	..	..	..	..	..
Phosphoric (Avl.)	..	..	..	..	..	..	..	..
Nitrogen	0·02	0·08	0·06	0·05	0·06	0·16	0·08	0·05

TABLE No. XIV.

The Punjab Soils.

ANALYSES OF THE WATER EXTRACT OF ALKALI SOILS.

Per cent on air dry fine earth..

No.	Locality and Description of sample	Total solids	Chlorides as NaCl	Carbonates as $Na_2\ Co_3$	Bicarbonates as $Na\ H\ Co_3$	Sulphates as $Na_2\ So_4$
1	Narwala Reh Farm, Lyallpur . .	2·49	0·234	*Nil*	*Nil*	*Nil*
2	Pinjripur, District Montgomery . .	1·412	0·083	*Nil*	0·068	1·10
3	Bara Farm, Montgomery . . .	0 852	*Nil*	0·070	0·103	*Nil*
4	Alkali land Mianchannu, District Multan	1·46	0·702	0·064	0·084	0·523
5	Alkali land Muzaffarabad, District Multan	1·28	*Nil*	0·237	0·256	*Nil*
6	Alkali land Tehsil Pind Dadan Khan, District Jhelum.	5·82	2·41	Trace.	0·007	*Nil*
7	Alkali land Khushab, District Shahpur .	4·35	3·18	*Nil*	0·006	*Nil*
8	Kallar lands, District Gujranwala . .	0·47	0·009	0·06	0·206	0·187
9	Alkali land Sahiwal, District Shahpur .	1·58	0·62	*Nil*	0·437	0·505

TABLE NO. XV.

The Punjab Soils.

ANALYSES OF BARA SOILS.

DESCRIPTION	1st 6″	2nd 6″	II ft.	III ft.	IV ft.	V ft.	VI ft.	VII ft.
Mechanical.								
Fine Gravel	*Nil*	0·04	*Nil*	0·25	0·21	0·36	0·30	0·3
Coarse sand	0·46	0·56	0·34	0·30	0·38	0·22	0·22	0·2
Fine sand	39·70	34·73	34·10	29·01	34·10	29·05	21·93	13·6
Silt	22·50	26·99	27·23	31·70	30·49	34·88	37·80	36·1
Fine silt	19·04	16·64	19·04	18·72	20·64	18·24	23·31	29·9
Clay	14·56	8·32	9·92	9·48	10·08	7·68	10·08	11·8
Chemical.								
Potash as K_2O	0·690	0·925	0·755	0·855	..	0·980	1·000	..
Phosphoric acid as P_2O_2	0·197	0·185	0·167	0·161	0·141	0·134	0·123	0·120
Lime as CaO	4·150	4·090	4·880	6·370	5·930	6·160	6·390	4·000
Magnesia as MgO	2·230	2·250	2·270	2·190	2·380	2·460	2·740	3·100
Iron and Aluminium (Fe_2O_3) Al_2O_3)	10·025	10·255	10·390	10·075	9·220	9·955	10·730	10·080
Potash (Avl.)	..	..	..	..	..	..	..	..
Phosphoric (Avl.)	..	..	..	..	..	..	..	..
Nitrogen (o/o on air dried soil)	0·030	0·027	0·027	0·027	0·021	0·008	0·032	0·03

TABLE No. XVI.

The Punjab Soils.

ANALYSES OF NORMAL SOILS OF MONTGOMERY COLONY.

Description	1st 6″	2nd 6″	II foot	III foot	IV foot	V foot	VI foot	VII foot
Mechanical.								
Fine Gravel	0·63	0·30	0·43	0·21	0·02	0·03	0·02	0·04
Coarse sand	0·63	0·53	0·50	0·66	0·43	0·37	0·34	0·16
Fine sand	39·56	30·56	19·10	24·58	22·43	26·04	16·47	8·22
Silt	18·47	23·58	26·83	27·51	36·65	38·55	45·42	51·39
Fine silt	18·88	18·72	26·66	24·0	21·92	17·76	19·76	23·46
Clay	13·12	13·60	14·56	13·12	8·88	6·88	8·16	8·32
Chemical.								
Potash as K_2O	0·730	1·070	0·570	0·630	0·590	0·710	0·725	0·925
Phosphoric acid as P_2O_5	0·164	0·1590	0·1500	0·1410	0·1380	0·1437	0·1535	0·1530
Lime as CaO	3·82	4·15	5·14	5·08	4·38	3·94	3·53	3·68
Magnesia as MgO	3·11	2·17	2·41	2·60	2·67	2·85	2·28	2·17
Iron and Aluminium (Fe_2O_3) Al_2O_3	7·950	9·265	10·350	10·575	10·895	10·320	9·480	9·935
NITROGEN (o/o on air dried soil)	0·0432	0·0399	0·0378	0·0388	0·0360	0·0345	0·0324	0·0312

Table XVII.

The Punjab Soils.

Analyses of Virgin lands (Nili Bar).

Locality	Kabullah		Between Kabullah and Tibi Lal Beg					
Description	1st 6″	2nd 6″	1st 6″	2nd 6″	2nd foot	3rd foot	4th foot	5th foot
Number	1	1	2	2	2	2	2	2
Mechanical.								
Fine Gravel	0·014	*Nil*	0·04	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
Coarse sand	3·10	3·06	11·91	12·12	9·26	7·31	9·04	6·77
Fine sand	48·39	38·10	45·94	39·05	35·67	55·25	74·48	77·35
Silt	22·92	28·28	11·45	17·12	19·00	16·92	7·68	6·92
Fine silt	14·04	17·84	18·56	26·42	21·18	11·04	4·04	3·92
Clay	9·36	9·84	15·92	11·84	13·44	7·20	4·24	4·08
Chemical.								
Potash as K_2O	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5	..	..	..	..	..	..	..	..
Lime as CaO	6·229	6·778	5·423	6·918	..	..	..	..
Magnesia as MgO	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3)	..	..	..	..	..	..	..	..
Potash (Avl.)	0·032	0·037	0·0302	0·023	..	..	..	..
Phosphoric (Avl.)	0·0023	0·065	0·0676	0·036	..	..	..	..
Matter soluble in water	0·106	0·168	0·152	0·082	..	..	..	..
Nitrogen (o/o on air dried soil)	..	..	..	..	..	..	..	..

TABLE No. XVII—*contd.*

The Punjab Soils—contd.

ANALYSES OF VIRGIN LANDS (NILI BAR)—*contd.*

LOCALITY	BETWEEN KABULLAH AND TIBI LAL BEG						SADULLAPUR		
DESCRIPTION	1st 6″	2nd 6″	2nd foot	3rd foot	4th foot	5th foot	1st 6″	2nd 6″	2nd foot
Number	3	3	3	3	3	3	4	4	4
Mechanical.									
Fine Gravel	*Nil*	*Nil*	*Nil*	*Nil*	0·024	0·10	*Nil*	*Nil*	*Nil*
Coarse sand	3·87	2·23	1·25	4·73	13·92	22·77	3·87	4·02	3·61
Fine sand	38·49	32·88	43·52	64·40	56·97	58·53	39·86	40·10	40·44
Silt	27·08	28·46	25·20	15·42	15·84	9·16	23·75	21·36	23·33
Fine silt	15·40	21·68	18·64	6·64	6·60	4·08	13·76	14·36	17·20
Clay	12·88	11·60	9·96	4·80	3·92	3·04	16·32	19·68	14·00
Chemical.									
Nitrogen	..	..	..	..	..	..	..	..	..
Potash as K_2O	..	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5	..	..	..	..	..	..	..	..	..
Lime as CaO	7·570	8·170	..	..	..	..	2·342	4·278	..
Magnesia as MgO	..	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	..	..	..	..	..	..	..
Potash (Avl.)	0·064	0·046	..	..	..	..	0·026	0·052	..
Phosphoric (Avl.)	0·063	0·019	..	..	..	..	0·0717	0·076	..
Matter soluble in water	0·756	0·390	..	..	..	..	0·232	0·196	..

TABLE No. XVII—*contd.*

The Punjab Soils—contd.

ANALYSES OF VIRGIN LANDS (NILI BAR)—*contd.*

LOCALITY	JAMLERA.			MATEWALA.			BAISAKHIWALA.		
DESCRIPTION	1st 6″	2nd 6″	3rd 6″	1st 6″	2nd 6″	3rd 6″	1st 6″	2nd 6″	3rd 6″
Number	5	5	5	6	6	6	7	7	7
Mechanical.									
Fine Gravel	*Nil*	*Nil*	*Nil*	*Nil*	0·10	*Nil*	*Nil*	0·10	*Nil*
Coarse sand	2·15	1·19	2·45	2·07	1·85	1·33	8·96	9·17	3·91
Fine sand	22·18	13·51	13·76	29·33	21·75	15·65	44·20	35·34	25·80
Silt	23·40	21·17	20·45	25·30	26·30	23·63	16·30	18·29	20·75
Fine silt	26·80	29·24	35·84	23·20	30·00	38·44	16·88	20·00	29·20
Clay	23·44	29·60	24·16	15·04	18·72	18·49	10·80	13·68	16·88
Chemical.									
Nitrogen	..	..	..	..	..	..	..	..	..
Potash as K_2O	..	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5 . .	..	..	..	..	..	..	..	..	..
Lime as CaO	1·479	4·415	2·769	3·809	4·542	4·542	4·153	4·166	5·186
Magnesia as MgO	..	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	..	..	..	..	..	..	..
Potash (Avl.)	0·041	0·037	0·024	0·022	0·022	0·032	0·017	0·022	0·067
Phosphoric (Avl.)	0·061	0·053	0·054	0·047	0·034	0·007	0·063	0·009	0·056
Matter soluble in water . . .	0·288	0·352	0·240	0·148	0·136	0·112	0·112	0·072	0·144

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BY

J. H. WALTON, M.A., M.Sc.
Imperial Agricultural Bacteriologist

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NITRIFICATION OF CALCIUM CYANAMIDE IN SOME INDIAN SOILS.

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Laboratory experiments and field trials had been carried out at Pusa with calcium cyanamide, or nitrolim, before the series of experiments to be described was undertaken, but no nitrification was found in Pusa soil in the original experiments, and no beneficial effects had been observed in the field trials.

As Pusa soil is a highly calcareous alluvium, containing upwards of thirty per cent. of calcium carbonate, the writer thought it quite possible that though this soil might be quite unsuitable for the application of calcium cyanamide, different results would be obtained in other Indian soils. Nitrification experiments with cyanamide in Pusa soil were therefore repeated, and in other Indian soils the nitrification of cyanamide nitrogen was compared with that of ammonium sulphate and of mustard cake. The mustard cake used had been extracted with ether to free it from oil. The cyanamide was free from dicyanodiamide.

The amounts of these materials used were calculated so as to add 30 mgms. of nitrogen to 100 gms. of soil. Water was added to the soil to bring the moisture content to the optimum for the action of the nitrifying bacteria. In general, the amount of water added was about one-third of the saturation capacity of the soil. Water was added every week to make up the loss due to evaporation. All soils were incubated at 30°C. The nitrate content of the soils was estimated by the phenol disulphonic acid method.

In the first series of experiments the soils used were from Pusa, Gujranwala in the Punjab, Sihar in the Central Provinces and Black Cotton soil from the Central Provinces. Gujranwala soil is a sandy loam, pH 8·1. Sihar soil is a sandy loam, pH 7·2. The Black Cotton soil is a heavy clay, pH 7·5. Estimations were carried on during only eight weeks in the Gujranwala soil, during twelve weeks in the Black Cotton soil, fourteen weeks in the Sihar soil but in the Pusa soil, in which the nitrification of cyanamide was expected to be slow or absent, they were carried on over

a period of thirty weeks. Tables I-IV show the results obtained. Differences in nitrate and ammonia content of the soils are illustrated in figure I.

TABLE I.

Nitrification in Gujranwala soil.

—	Nitrogen as	Mgms. Nitrogen per 100 gms. soil after week.					
		1	2	3	4	6	8
Soil + Cyanamide	NO_3	*nil*	*nil*	1·2	*nil*	1·8	2·1
	NO_2	0·2	0·15	0·12	0·15	0·10	..
	NH_3	..	28·6	19·3	22·7	17·6	14·3
Soil + Ammonium sulphate	NO_3	7·5	24·0	21·0	23·3	25·2	26·3
	NO_2	3·4	0·12	0·08	0·08	0·05	0·07
	NH_3	..	3·4	4·2	2·5	2·5	5·0
Soil+Cake	NO_3	5·4	18·0	14·4	15·0	21·6	18·8
	NO_2	4·76	0·06	0·04	0·04	0·02	0·08
	NH_3	..	3·4	3·4	3·4	2·5	5·9
Soil alone (control)	NO_3	1·8	0·0	2·4	2·1	2·7	3·0
	NO_2	0·0	0·0	0·0	0·0	0·0	0·01
	NH_3	..	3·4	5·0	3·4	2·5	5·0

TABLE II.

Nitrification in Black Cotton soil

—	Nitrogen as	Mgms. Nitrogen per 100 gms. soil after week.							
		1	2	3	4	6	8	10	12
Soil + Cyanamide.	NO_3	1·4	1·5	1·7	2·1	3·5	3·6	4·8	6·0
	NO_2	0·02	0·16	0·23	0·21	0·04	0·02	0·01	0·01
	NH_3	10·1	10·6	13·9	12·3	12·3	9·5	2·2	*nil*
Soil + Ammonium sulphate.	NO_3	2·0	3·2	5·4	6·3	8·4	14·3	16·5	18·0
	NO_2	0·27	0·06	0·04	0·03	0·02	0·02	0·01	0·01
	NH_3	2·9	13·4	11·8	9·0	7·8	7·3	7·3	5·6
Soil + Cake	NO_3	1·8	2·4	3·6	4·2	8·4	13·5	16·5	16·5
	NO_2	0·11	0·11	0·06	0·05	0·02	0·01	0·01	0·01
	NH_3	7·8	4·5	8·9	10·1	7·8	6·2	8·0	2·8

Initial content of soil :—NO_3 = 1·20 ; NO_2 = 0·03 ; NH_3 = 1·7.

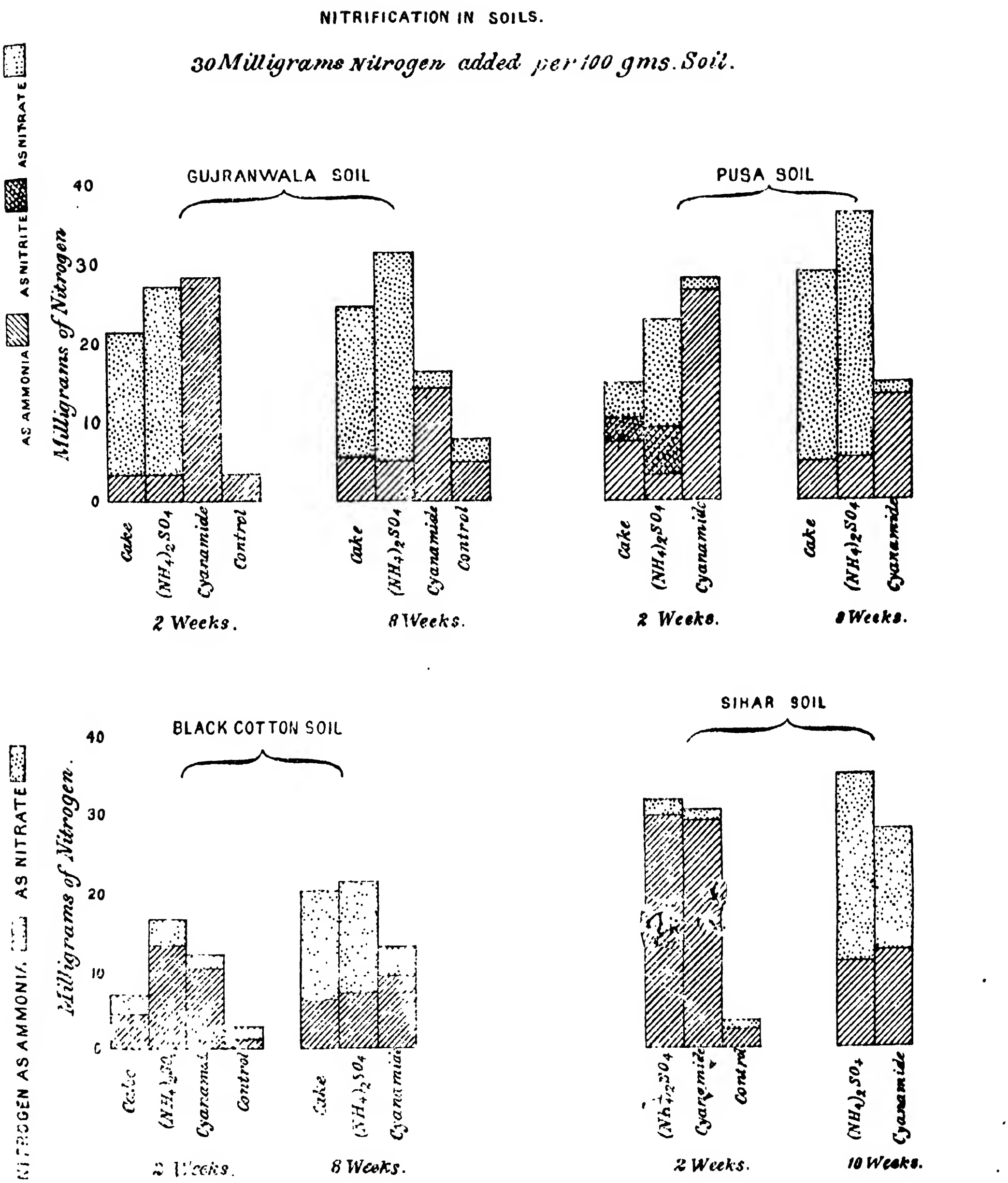
NITRIFICATION IN SOILS.
30 Milligrams Nitrogen added per 100 gms. Soil.
AS AMMONIA
AS NITRITE
AS NITRATE
Milligrams of Nitrogen
GUJRANWALA SOIL
PUSA SOIL
Cake
$(NH_4)_2SO_4$
Cyanamide
Control
2 Weeks.
8 Weeks.
BLACK COTTON SOIL
SIHAR SOIL
NITROGEN AS AMMONIA
AS NITRATE
10 Weeks.

Fig. 1.

Table III.

Nitrification in Sihar soil.

—	Nitrogen as	Mgms. nitrogen per 100 gms. soil after week.							
		1	2	4	6	8	10	12	14
Soil + Cyanamide.	NO_3	1·2	1·4	1·5	2·4	3·0	15·8	24·0	30·0
	NO_2	0·04	0·02	0·12	0·51	3·92	0·04	0·23	0·14
	NH_3	31·4	20·5	29·2	26·5	18·5	12·4	6·3	0·8
Soil + Ammonium sulphate.	NO_3	1·2	2·0	3·9	17·4	17·4	24·0	25·5	30·0
	NO_2	0·03	0·08	0·02	0·07	0·06	0·03	0·03	0·06
	NH_3	26·9	29·8	22·7	15·5	13·9	11·2	10·5	7·6

Initial content of soil :—NO_3 =1·4 ; NO_2 =0·01 ; NH_3 2·2.

Table IV.

Nitrification in Pusa soil.

—	Nitrogen as	Mgms. nitrogen per 100 gms soil after week.										
		1	2	4	6	8	10	12	15	19	24	36
Soil + Cyanamide	NO_3	1·2	1·2	1·7	1·7	1·5	1·7	1·7	1·7	1·6	1·7	1·1
	NO_2	0·02	0·02	0·05	0·03	0·01	0·12	0·27	..	0·02	0·12	0·05
	NH_3	26·9	13·0	11·1	13·9	13·4	11·8	12·2	7·6	12·2	6·0	10·1

Table IV (*a*).

Nitrification in Pusa soil.

—	Nitrogen as	Mgms. nitrogen per 100 gms. soil after week.					
		1	2	3	4	6	8
Soil + Ammonium sulphate.	NO_3	4·2	14·4	28·8	20·4	28·8	31·2
	NO_2	3·89	5·83	0·08	0·12	trace	*nil*
	NH_3	3·9	3·4	2·5	2·8	5·0	5·6
Soil + Cake	NO_3	2·7	4·2	15·6	24·0	24·0	24·0
	NO_2	1·0	3·11	0·16	trace	0·06	trace
	NH_3	18·5	7·6	5·9	14·3	11·0	5·0

TABLE IV (*b*).

Nitrification in Pusa soil.

—	Nitrogen as	Mgms. nitrogen per 100 gms. soil after week.			
		1	2	3	4
Soil + Ammonium sulphate	NO_3	1·2	3·6	24·0	31·2
	NO_2	2·12	3·20	0·04	0·08
	NH_3	24·1	11·3	6·2	2·8
Soil + Cake	NO_3	1·2	4·8	18·0	18·0
	NO_2	1·09	7·00	0·58	0·04
	NH_3	16·8	8·0	8·4	6·7
Soil alone	NO_3	*nil*	3·8	trace	4·5
	NO_2	0·39	*nil*	*nil*	*nil*
	NH_3	4·2	1·7	1·7	2·3

The results for Pusa, Gujranwala, Sihar and Black Cotton soils showed that only in Sihar soil was there any considerable amount of the added cyanamide nitrogen nitrified, and then only after ten weeks' incubation.

The amount of nitrogen added, 30 mgms. per 100 gms. soil, is far higher than that which is added in the field.

Further experiments were therefore started with the Pusa, Gujranwala and Black cotton soils in which only 5 or 10 mgms. of nitrogen was added as cyanamide and other experiments were started with a further selection of soils, adding 30 mgms. of nitrogen in one set, and 5 mgms. in another, per 100 gms. soil.

Table V (*a*) shows the results obtained with Pusa soil up to 21 weeks incubation. The experiment was repeated and the results shown in Table V (*b*).

TABLE V (*a*).

Nitrification of cyanamide in Pusa soil.

—	Nitrogen as	Mgms. nitrogen per 100 gms. soil after week.							
		1	2	4	6	7	10	14	21
Soil + 10 mgms. nitrogen per 100 gms. soil	NO_3	1·9	1·5	1·5	1·8	1·2	1·5	3·6	3·3
	NO_2	0·06	0·06	0·06	0·06	0·05	0·05	..	0·08
	NH_3	6·6	5·0	8·4	9·7	8·4	9·7	10·9	..
Soil + 5 mgms. nitrogen per 100 gms. soil	NO_3	1·9	1·5	1·5	1·8	1·8	3·6	4·8	8·4
	NO_2	0·09	0·07	0·05	..	0·04	0·04	0·08	0·03
	NH_3	7·9	5·5	7·6	6·3	7·6	7·6	8·4	..
Soil alone	NO_3	1·2	..	4·5	9·0	8·4	4·8	..	..
	NO_2	0·04	..	0·05	..	0·02	0·24	..	..
	NH_3	3·4	..	0·8	3·4	2·5	..	..	..

TABLE V (*b*).

Nitrification of cyanamide in Pusa soil.

—	Nitrogen as	Initial.	Mgms. nitrogen per 100 gms. soil after month.					
			2	3	4	5	6	7
Soil + 10 mgms. nitrogen per 100 gms. soil.	NO_3	..	3·3	9·0	11·4	12·0	13·5	13·5
	NH_3	..	5·0	8·1	4·8	4·2	6·0	4·2
Soil + 5 mgms. nitrogen per 100 gms. soil.	NO_3	..	7·2	8·4	9·6	12·0	13·5	13·5
	NH_3	..	4·6	7·2	5·4	3·4	4·8	4·2
Soil alone . . .	NO_3	1·4	6·0	7·2	6·6	9·0	12·0	10·5
	NH_3	3·6	5·9	5·1	4·2	2·5	4·8	2·5

TABLE VI.

Nitrification of cyanamide in Gujranwala soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. Soil. Mgms. nitrogen after week.						
		1	2	3	4	5	6	7
Soil + Cyanamide .	NO_3	1·1	1·2	1·8	2·4	2·1	3·0	2·7
	NO_2	0·03	..	0·17	*nil*	*nil*	*nil*	*nil*
	NH_3	5·6	5·6	6·7	7·8	5·6	4·5	5·6
Soil alone . .	NO_3	1·2	1·8	2·7	3·0	3·0	3·0	2·4
	NO_2	0·7	0·04	0·03	*nil*	0·02	*nil*	0·04
	NH_3	3·4	4·5	2·3	5·6	5·6	4·5	2·2

TABLE VII (*a*).

Nitrification in Black Cotton soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil. Mgms. nitrogen after week.						
		1	2	3	4	5	6	8
Soil+Cyanamide	NO_3	1·5	1·8	2·4	2·7	3·0	3·0	3·6
	NO_2	0·05	0·07	0·02	0·03	..	0·03	0·02
	NH_3	5·9	3·4	4·2	2·9	2·1	4·2	..
Soil+Ammonium sulphate.	NO_3	1·5	2·3	3·0	4·5	5·1	5·4	5·4
	NO_2	0·17	0·05	0·02	0·02	..	0·02	0·02
	NH_3	4·6	2·9	1·7	4·2	2·9	2·5	..
Soil+Cake	NO_3	1·5	1·9	2·7	3·0	3·3	4·8	4·8
	NO_2	0·14	0·19	0·03	0·01	..	0·02	0·02
	NH_3	3·8	2·5	2·9	2·6	2·9	3·4	..
Soil alone	NO_3	1·95	..	..	..	4·5	4·8	4·8
	NO_2	0·03	..	..	..	..	0·02	0·03
	NH_3	1·70	..	..	..	1·7	1·3	1·5

As nitrification was slow, the experiment was repeated and determinations done at longer intervals of time.

TABLE VII (*b*).

Nitrification in Black Cotton soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil. Mgms. nitrogen after month.					
		2	3	4	5	6	7
Soil + Cyanamide	NO_3	4·5	6·0	7·2	9·0	10·8	7·8
	NH_3	5·0	2·7	2·4	1·7	2·1	1·4
Soil+Ammonium sulphate	NO_3	4·8	6·0	6·0	9·0	9·6	9·0
	NH_3	4·5	2·7	1·8	1·5	2·4	3·4
Soil+Cake	NO_3	4·8	6·0	7·2	7·8	9·0	7·8
	NH_3	5·6	2·1	2·4	1·5	3·0	2·2
Soil alone	NO_3	4·2	3·9	4·8	4·8	5·4	3·9
	NH_3	1·7	1·8	1·8	1·6	3·0	3·4

Table V (*a*) shows that for ten weeks there is less nitrate nitrogen in the soil to which cyanamide had been added than in the soil alone, and after that, up to the twenty-first week, there was less nitrification in the soil with 10 mgms. cyanamide nitrogen added than in that with only 5 mgms. of added nitrogen. The repetition of the experiment, the results of which are given in Table V (*b*), shows that some of the added nitrogen had been nitrified in three months, and the maximum increase over the control occurred in four months. The increase in nitrate with the 5 mgms. dose of nitrogen is equal to 60 per cent. of the added nitrogen, that for 10 mgms. dose to 48 per cent.

In the Gujranwala soil, none of the added 5 mgms. nitrogen appeared to have been nitrified in seven weeks (Table VI).

In Black Cotton soil, in which cake and sulphate of ammonia had nitrified only slowly, the experiment was repeated using 5 mgms. doses of nitrogen with these manures as well as with cyanamide.

In the first trial (Table VII *a*), the added nitrogen did not appear to nitrify in eight weeks, but in the next trial (Table VII *b*), though again there were only traces of the added nitrogen nitrified in two months, after three months 42 per cent. had been nitrified, and after six months the whole of the cyanamide nitrogen appeared to have been nitrified, and also 84 per cent. of that applied as sulphate of ammonia and 72 per cent. of that applied as mustard cake.

The other soils in which nitrification was tested were from the following localities. Kalol, Northern Bombay, a heavy loam, pH 7·3

Chinsurah, Southern Bengal, clay, pH 7·2

Sialkot, Punjab, a heavy loam, pH 7·3

Ranchi, Chota Nagpur, Upland soil, Coarse, sandy, pH 6·2

Ranchi, Chota Nagpur, Intermediate soil, Heavy loam, pH 6·0

Ranchi, Chota Nagpur, Valley soil, Clay, pH 6·9

Cawnpore, United Provinces, light loam (Gangetic alluvium), pH 7·6

Kalianpur, United Provinces, Sandy loam, pH 7·3

Karimganj, Sylhet, Heavy loam (Paddy soil), pH 4·9

The tables which follow give the results obtained with these soils.

Table VIII (*a*).

Nitrification in Kalol soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil. Nitrogen after week.							
		1	3	7	11	15	20	24	30
Soil + Cyanamide.	NO_3	0·4	0·5	0·6	0·7	1·2	18·8	24·0	21·0
	NO_2	0·04	0·01	0·04	0·02	0·03	0·01	..	..
	NH_3	21·7	24·6	22·3	21·8	19·3	4·5	4·5	3·7
Soil + Ammonium sulphate.	NO_3	1·8	7·9	15·6	16·5	18·0	21·0	22·5	21·0
	NO_2	0·03	0·02	0·02	0·02	0·01	0·02	..	..
	NH_3	25·0	20·0	16·8	13·4	11·8	11·2	12·3	10·7
Soil + Cake .	NO_3	2·3	12·0	16·2	18·0	19·5	22·5	24·0	24·0
	NO_2	0·23	0·02	0·02	0·02	..	0·04	0·04	0·02
	NH_3	15·7	6·2	5·0	2·5	2·1	4·5	3·4	2·7

Table VIII (*b*).

Nitrification in Kalol soil.

—	Nitrogen as.	Initial.	5 Mgms. nitrogen added per 100 gms. soil. Nitrogen after week.						
			1	2	3	4	5	6	8
Soil + Cyanamide.	NO_3	..	0·8	2·3	3·0	4·5	5·7	6·0	6·6
	NO_2	..	0·02	0·02	0·02	0·02	..	0·03	0·03
	NH_3	..	7·8	5·0	6·7	3·7	2·9	2·5	..
Soil alone .	NO_3	0·5	..	..	..	..	4·2	5·4	5·1
	NO_2	0·04	..	..	..	..	0·02	0·06	0·11
	NH_3	2·4	..	..	..	..	2·5	1·3	..

TABLE VIII (c).

Nitrification in Kalol soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil.	
		Initial.	After two months.
Soil + Cyanamide	NO_3	..	9·6
	NH_3	..	3·9
Soil alone	NO_3	0·4	4·5
	NH_3	3·8	3·4

TABLE IX (a).

Nitrification in Chinsurah soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.										
		Mgms. nitrogen after week.										
		1	3	7	11	15	20	24	30	33	36	40
Soil + Cyanamide	NO_3	0·3	0·5	1·1	1·4	2·0	3·0	2·7	10·8	15·0	15·0	16·5
	NO_2	0·0[illegible]	0·01	0·02	0·02	..	0·01	..	0·05	0·02	0·02	0·02
	NH_3	15·4	9·5	14·0	7·6	9·8	13·4	13·4	5·3	2·7	3·0	..
Soil + Ammonium sulphate.	NO_3	0·9	3·4	9·6	16·5	19·5	21·0	25·5	19·5	..	..	.
	NO_2	0·02	0·01	0·02	0·02	0·02	0·04	..	0·02	..	..	..
	NH_3	8·4	11·9	11·3	2·9	1·5	4·5	3·9	2·1	..	..	..
Soil + Cake	NO_3	0·6	3·0	8·4	16·5	16·5	16·5	22·5	18·0	..	..	..
	NO_2	0·10	0·05	0 02	0·03	0·04	0·08	0·07	0·05	..	..	..
	NH_3	13·3	9·0	6·4	1·7	1·0	3·4	3·4	2·7	..	..	..

Table IX (*b*).

Nitrification in Chinsurah soil.

—	Nitrogen as	Initial	5 Mgms. nitrogen added per 100 gms. soil as cyanamide. 10 Mgms. nitrogen added per 100 gms. soil as cake or ammonium sulphate. Mgms. nitrogen after week.							
			1	2	4	6	7	10	14	21
Soil + Cyanamide	NO_3	..	0·6	0·8	1·5	3·6	3·6	5·4	5·4	7·2
	NO_2	..	0·04	0·06	0 02	..	..	..	..	0·04
	NH_3	..	7·6	5·6	2·5	0·8	1·3	2·9	2·5	1·9
Soil + Ammonium sulphate.	NO_3	..	1·0	1·3	2·9	6·0	6·3	7·5	7·2	10·8
	NO_2	..	0·09	0·02	0·02	..	..	0·03	..	0·03
	NH_3	..	3·5	4·5	2·9	1·3	0·8	2·9	3·4	0·9
Soil + Cake	NO_3	..	0·8	0·9	2·6	6·0	5·4	6·8	7·2	9·6
	NO_2	..	0·08	0·12	0·04	..	0·02	0·05	..	0·0
	NH_3	..	5·2	6·2	3·4	1·3	1·7	1·7	3·4	1·4
Soil alone	NO_3	0·4	..	..	2·1	4·8	3·6	5·4	..	..
	NO_2	0·05	..	..	0·02	..	0·02	..	..	..
	NH_3	3·9	..	..	2·1	*nil*	0·8	2·1	..	..

Table IX (*c*).

Nitrification in Chinsurah soil.

—	Nitrogen as	Initial	5 Mgms. nitrogen added per 100 gms. soil as cyanamide. 10 Mgms. nitrogen added per 100 gms. soil as cake or ammonium sulphate. Mgms. nitrogen after month.				
			2	3	4	6	7
Soil + Cyanamide	NO_3	..	4·5	5·4	5·4	6·6	6·6
	NH_3	..	2·8	2·3	1·6	2·4	1·7
Soil + Ammonium sulphate	NO_3	..	6·0	7·2	7·2	8·4	7·8
	NH_3	..	3·9	2·3	1·6	2·4	2·5
Soil + Cake	NO_3	..	6·0	7·2	7·2	8·4	7·8
	NH_3	..	2·2	2·7	1·6	2·4	4·2
Soil alone	NO_3	0·3	3·0	3·3	3·6	4·8	5·4
	NH_3	2·1	3·9	2·4	1·6	3·0	1·2

Table X (*a*).

Nitrification in Sialkot soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.					
		Mgms. nitrogen after week.					
		1	2	3	4	6	8
Soil+Cyanamide	NO_3	traces	1·5	1·5	1·2	1·5	2·7
	NO_2	traces	..	..	..	..	..
	NH_3	20·2	19·3	23·5	23·1	20·2	20·2
Soil+Ammonium sulphate	NO_3	8·3	25·5	30·0	27·8	27·8	29·3
	NO_2	2·4	0·5	0·1	0·1	0·1	0·1
	NH_3	6·7	3·4	2·5	4·2	2·2	3·4
Soil+Cake	NO_3	9·8	17·3	20·3	21·8	23·3	20·3
	NO_2	1·1	0·1	traces	..	..	..
	NH_3	4·2	4·2	2·5	2·1	3·4	..
Soil alone	NO_3	1·5	1·5	2·1	2·1	2·7	3·6
	NO_2	*nil*	*nil*	0·1	*nil*	0·1	0·1
	NH_3	2·5	3·4	0·8	4·2	3·4	4·5

Table X (*b*).

Nitrification in Sialkot soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil.						
		Mgms. nitrogen after week.						
		1	2	3	4	5	6	7
Soil+Cyanamide	NO_3	2·4	4·2	6·8	6·6	4·2	5·4	5·4
	NH_3	6·7	6·7	3·4	5·6	5·6	3·4	3·4
Soil alone	NO_3	2·1	2·1	3·3	3·0	2·4	3·3	3·0
	NH_3	4·5	..	3·4	3·4	4·2	3·4	2·2

TABLE XI (*a*).

Nitrification in Ranchi Upland soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.										
		Mgms. nitrogen found after week.										
		1	2	4	6	10	14	18	20	24	28	30
Soil + Cyanamide	NO_3	0·9	1·0	traces	traces	traces	traces	traces	traces	traces	1·1	10·8
	NO_2	traces	traces	traces	traces	traces	traces	traces	traces	0·1	3·6	0·0
	NH_3	20·4	22·4	18·8	20·0	18·8	20·8	18·4	18·4	17·2	11·2	6·8
Soil + Ammonium sulphate.	NO_3	0·6	0·9	2·7	3·3	3·6	4·2	6·0	6·0	9·6	9·6	..
	NO_2	traces	traces	traces	traces	traces	traces	traces	traces	traces	traces	traces
	NH_3	26·4	28·8	20·8	19·2	17·6	18·4	16·1	16·8	14·8	13·6	..
Soil + Cake	NO_3	0·5	1·2	6·3	12·0	13·2	13·2	18·0	12·0	13·2	10·8	..
	NO_2	..	0·1	..	..	0·1	*nil*	0·1	0·1	0·1	0·1	..
	NH_3	16·0	18·8	9·6	7·2	1·8	1·8	1·0	3·6	2·8	3·2	..
Soil alone	NO_3	1·5	1·5	..	2·1	2·7	2·1	2·1	2·1	3·0	..	3·6
	NO_2	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*
	NH_3	0·8	0·4	..	0·4	2·1	1·2	*nil*	0·4	0·8	..	1·6

TABLE XI (*b*).

Nitrification of cyanamide in Ranchi Upland soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil.				
		Mgms. nitrogen found after week.				
		1	2	4	8	12
Soil + Cyanamide	NO_3	0·9	1·5	5·4	6·6	6·6
	NO_2	*nil*	*nil*	*nil*	*nil*	*nil*
	NH_3	4·4	2·8	0·4	0·8	0·8

Control soil alone, See Table XI (*a*) above

TABLE XII (*a*).

Nitrification in Ranchi Intermediate soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.										
		Mgms. nitrogen per 100 gms. soil after week.										
		1	2	4	6	10	14	18	20	24	28	32
Soil + Cyanamide	NO_3	0·3	0·6	*nil*	trace	trace	trace	2·7	4·8	12·0	13·2	21·6
	NH_3	20·4	23·6	20·0	22·4	20·4	20·8	19·2	15·2	10·0	5·2	1·6
Soil + Ammonium sulphate.	NO_3	0·51	1·2	2·7	6·0	6·6	10·8	13·2	12·0	14·4	13·2	19·2
	NH_3	25·2	25·2	16·8	16·4	15·2	13·2	12·8	12·0	10·0	8·4	7·6
Soil + Cake	NO_3	0·2	0·6	2·7	12·0	14·4	21·6	24·0	24·0	24·0	16·8	..
	NH_3	14·0	19·2	12·8	7·2	4·4	2·8	1·6	1·2	1·6	1·6	..
Soil alone	NO_3	1·1	1·2	..	1·4	2·1	2·1	2·1	1·8	2·7	3·6	3·6
	NH_3	0·4	1·6	..	0·8	1·6	1·6	0·4	0·4	0·8	1·6	0·8

Only traces of nitrite were ever found.

TABLE XII (*b*).

Nitrification in Ranchi Intermediate soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil.				
		Mgms. nitrogen found after week.				
		1	2	4	8	12
Soil + Cyanamide	NO_3	0·6	1·1	4·8	6·0	6·0
	NH_3	4·4	3·6	0·4	0·8	1·2

For soil alone see Table XII (*a*) above.

Table XIII (*a*).

Nitrification in Ranchi Valley soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil. Mgms. nitrogen found after week.									
		1	2	4	8	12	16	21	25	29	34
Soil + Cyanamide	NO_3	0·5	traces	traces	traces	traces	3·0	20·4	19·2	21·6	21·6
	NH_3	17·6	18·0	18·0	19·6	18·4	17·2	2·8	2·0	2·8	2·0
Soil + Ammonium sulphate	NO_3	1·4	5·7	12·0	21·6	24·0	24·0	24·0	19·2	..	..
	NH_3	20·8	14·8	9·2	4·0	4·0	3·6	2·8	2·8	..	..
Soil + Cake	NO_3	0·6	5·4	14·4	19·2	19·2	21·6	21·6	16·8	..	..
	NH_3	13·2	7·6	2·4	2·4	2·8	2·8	2·0	1·6	..	..
Soil alone	NO_3	1·1	1·2	1·5	2·1	2·4	2·4	2·7	3·6	4·2	4·8
	NH_3	0·8	1·6	1·6	2·0	1·6	0·8	1·2	1·2	2·4	1·6

Only traces of nitrite were ever found.

Table XIII (*b*)

Nitrification in Ranchi Valley soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil. Mgms. nitrogen found after week.					
		1	2	4	8	12	16
Soil + Cyanamide	NO_3	0·6	1·1	3·0	4·8	5·4	6·0
	NH_3	4·4	2·8	1·6	1·6	2·4	2·0

For soil alone, see Table XIII (*a*) above.

TABLE XIV (*a*).

Nitrification in Cawnpore soil.

	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.								
		Mgms. nitrogen found after week.								
		1	2	6	10	14	16	21	25	29
Soil + Cyanamide	NO_3	trace	1·4	0·6	0·9	0·6	0·8	0·6	0·8	0·6
	NO_2	trace	0·03	trace	trace	*nil*	trace	traces	traces	*nil*
	NH_3	15·2	14·8	14	11·8	14·0	13·6	13·2	12·4	10·0
Soil + Ammonium sulphate.	NO_3	12·0	21·6	24·0	31·2	26·4	26·4	21·0	24·0	..
	NO_2	0·72	0·06	0·04	0·03	0·02	0·03	0·05	0·05	..
	NH_3	7·2	2·8	1·6	2·4	2·4	2·1	2·4	2·0	..
Soil + Cake	NO_3	10·8	13·2	16·8	20·4	21·6	24·0	21·6	24·0	..
	NO_2	0·18	0·04	0·02	0·02	0·03	0·02	0·06	0·04	..
	NH_3	2·0	1·6	1·6	2·8	2·0	2·0	2·4	1·6	..
Soil alone	NO_3	1·7	2·0	3·0	3·6	3·9	1·2	1·2	5·4	6·0
	NO_2	traces only								
	NH_3	0·8	1·6	0·8	2·0	2·0	0·4	1·2	1·6	2·4

TABLE XIV (*b*).

Nitrification in Cawnpore soil.

	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil.							
		Mgms. nitrogen found after week.							
		1	2	6	10	14	16	21	25
Soil+Cyanamide.	NO_3	2·7	4·8	5·4	6·6	6·6	6·0	7·8	7·8
	NH_3	2·4	1·6	1·6	1·6	1·6	1·6	2·0	0·8

For soil alone, see Table XIV (*a*) above.

Table XV (*a*).

Nitrification in Kalianpur soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.								
		Mgms. nitrogen found after week.								
		1	2	6	10	11	16	21	25	29
Soil + Cyanamide	NO_3	trace	0·8	0·3	0·6	0·5	0·5	0·5	0·8	0·8
	NO_2	Never more than traces.								
	NH_3	11·2	12·1	10·8	12·4	12·8	10·3	11·2	10·1	8·0
Soil + Ammonium sulphate.	NO_3	3·0	5·4	10·8	16·8	15·6	11·4	16·8	16·8	..
	NO_2	Never more than traces								
	NH_3	14·0	12·8	6·4	6·8	5·2	3·6	4·0	3·2	..
Soil + Cake	NO_3	1·5	6·6	12·0	16·8	15·6	14·4	11·4	16·8	..
	NO_2	0·72	0·18	trace, only						
	NH_3	5·6	3·6	2·0	4·0	3·2	2·8	3·2	2·4	..
Soil alone	NO_3	1·1	1·2	1·4	1·8	1·5	1·8	1·8	2·1	2·1
	NO_2	Traces only.								
	NH_3	1·2	3·2	1·6	3·2	2·4	0·4	0·4	0·8	2·4

Table XV (*b*).

Nitrification in Kalianpur soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil.							
		Mgms. nitrogen found after week.							
		1	2	6	10	14	16	21	25
Soil + Cyanamide.	NO_3	trace	2·1	2·4	4·2	3·6	3·0	1·2	1·2
	NH_3	2·8	2·4	1·2	2·4	1·6	2·0	2·0	0·8

For soil alone, see Table XV (*a*) above.

TABLE XVI (*a*).

Nitrification in Karimganj soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms, soil.								
		Mgms. nitrogen found after week.								
		1	2	6	11	15	19	24	28	32
Soil + Cyanamide	NO_3	trace	trace	1·7	13·2	14·4	19·2	21·6	21·6	15·6
	NO_2	Traces only.								
	NH_3	27·2	27·6	30·0	15·2	13·6	11·6	11·2	12·0	12·0
Soil + Ammonium sulphate	NO_3	trace	trace	0·5	0·8	0·8	0·9	0·9	0·9	traces
	NO_2		Always less than 0·1.							
	NH_3	26·4	26·8	28·0	27·2	29·2	30·0	27·6	26·8	26·0
Soil + Cake	NO_3	trace	trace	1·7	4·2	3·0	2·1	2·1	3·3	3·0
	NO_2	trace	trace	trace	trace	0·1	0·1	0·1	0·1	0·1
	NH_3	16·8	18·0	19·2	17·2	16·4	18·4	18·0	16·4	17·2
Soil alone	NO_3	trace	trace	1·2	3·6	3·0	3·6	1·5	2·7	trace
	NO_2	trace	trace	trace	trace	0·04	0·2	0·04	0·05	0·04
	NH_3	5·6	5·6	5·6	3·2	3·6	2·8	4·4	4·8	5·2

TABLE XVI (*b*).

Nitrification in Karimganj soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms, soil								
		Mgms nitrogen found after week.								
		1	2	6	11	15	19	24	28	32
Soil + Cyanamide	NO_3	trace	trace	1·5	1·2	3·6	4·8	1·4	2·7	1·4
	NH_3	7·6	8·0	7·6	6·8	5·6	5·6	7·2	6·8	6·8

For Soil alone, see Table XVI (*a*)

TABLE XVI (*c*).

Nitrification in Karimganj soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil. Mgms. nitrogen found after week. 1	5	8	13	17
Soil + Cyanamide	NO_3	trace	trace	1·2	6·0	12·0
	NH_3	28·0	28·0	30·0	16·8	15·6
Soil + Ammonium sulphate	NO_3	trace	*nil*	*nil*	*nil*	trace
	NH_3	26·8	29·6	30·4	26·4	31·2
Soil + Cake	NO_3	trace	trace	1·2	1·4	5·4
	NH_3	17·2	12·8	22·0	18·8	20·4
Soil alone	NO_3	trace	trace	1·2	2·7	3·6
	NH_3	4·0	5·6	6·0	4·8	3·6

TABLE XVI (*d*).

Nitrification in Karimganj soil.

—	Nitrogen as	5 Mgms. nitrogen added per 100 gms. soil. Mgms. nitrogen found after week. 1	5	8	13	17
Soil + Cyanamide	NO_3	trace	trace	1·2	3·6	4·8
	NH_3	8·4	8·8	9·6	6·0	7·2

Soil alone, see Table XVI (*c*).

In the Kalol soil with the 30 mgms. dose of nitrogen, nitrification of the ammonium sulphate and cake had begun and given appreciable quantities of nitrate at the end of three weeks, but no nitrification of the cyanamide had taken place at the end of 15 weeks. Between the 15th and 20th weeks, however, vigorous nitrification of the cyanamide had set in, and the amount of nitrate found in the

20th week was not much less than that in the other lots of soil, and had reached those amounts by the twenty-fourth week. (Table VII *a*). When a 5 mgms. dose of nitrogen was given, nitrification proceeded slowly, and at the end of six weeks, 1·5 mgm. of the added nitrogen was nitrified. No further increase over the control was found in eight weeks (Table VIII *b*), but on repeating the experiment, and doing the first estimation of nitrate after two months, all the added nitrogen was found to be nitrified.

In the Chinsurah soil, nitrification of cake and ammonium sulphate in the 30 mgms. dose proceeded slowly. Nitrification of the cyanamide began only between the twenty-fourth and thirtieth week (Table IX *a*).

With the smaller doses of 5 mgms. nitrogen, only 42 per cent. of the added nitrogen as cyanamide was nitrified in three months, and no further increase but a decrease was found after seven months. About the same proportion of the ammonium sulphate and cake (each added in doses to give 10 mgms. nitrogen), were nitrified. (Tables IX *b* and IX *c*).

In Sialkot soil, there was no nitrification of cyanamide nitrogen in eight weeks with the 30 mgms. dose, but nitrification of cake and ammonium sulphate was rapid. In three weeks :3 per cent. of the ammonium sulphate nitrogen had been nitrified, and 60 per cent. of that of the cake. (Table X *a*).

When the 5 mgms. dose of nitrogen was given as cyanamide, nitrification was unchecked and 70 per cent. of the added nitrogen was nitrified at the end of the third week (Table X *b*).

Nitrification in Ranchi Upland soil had previously been found to be very slow, or even negligible. From the results given in Table XI (*a*), it will be seen that in fourteen weeks only 10 per cent. of the ammonium sulphate nitrogen had been nitrified, and in twenty-four weeks only 22 per cent. The nitrogen supplied in cake nitrified more rapidly, and nitrification had started by the end of the fourth week, and 36 per cent. had been nitrified by the end of the fourteenth week, rising to 56 per cent. at the end of the eighteenth week, but thereafter the nitrate content fell. No nitrification of the cyanamide nitrogen took place till after the twenty eighth week, when it set in vigorously, and 30 per cent. of the added nitrogen was recovered as nitrate after thirty weeks' incubation.

With the 5 mgms. dose of cyanamide nitrogen, nitrification started between the second and fourth weeks, when 66 per cent. of the added nitrogen was recovered as nitrate. (Table XI *b*).

Nitrification in the Ranchi intermediate soil was more vigorous than in the Upland soil. It again progressed more rapidly, and to a greater extent, when the nitrogen was supplied as cake than when it was supplied as ammonium sulphate, and was weakest with cyanamide; the nitrification of cyanamide nitrogen had started by the end of the twentieth week, and by the thirty-second week had surpassed that of sulphate of ammonia. Thirty five per cent of the nitrogen of the cake had nitrified at the end of six weeks, rising to 73 per cent. after eighteen weeks.

With the 5 mgms. dose of nitrogen as calcium cyanamide, nitrification had started vigorously by the end of the fourth week, and about 70 per cent. was nitrified by the eighth week.

The Ranchi Valley soil, which consists of the fine particles washed down from the higher levels, was much more favourable for nitrification than the other Ranchi soils. Nitrification of sulphate of ammonia had started by the end of the second week, and by the eighth week 65 per cent. of the added nitrogen was recovered as nitrate, and this surpassed the corresponding figure for cake, namely 57 per cent. Nitrification of cyanamide appeared to be starting at the end of the sixteenth week, and at the end of the twenty-first week 59 per cent. of the added nitrogen was recovered as nitrate. (Table XIII *a*).

With a 5 mgms. dose of nitrogen as cyanamide, nitrification had again progressed well by the end of the 4th week. (Table XIII *b*).

In the Cawnpore soil, nitrification of cake and ammonium sulphate had started at the end of one week but was absent where the 30 mgms. dose of nitrogen had been added as cyanamide, even after twenty-nine weeks. (Table XIV *a*). When the dose of cyanamide was reduced so as to add only 5 mgms. nitrogen, nitrification had proceeded so fast that in two weeks 64 per cent. of the added nitrogen was recovered as nitrate, and in ten weeks nitrification was complete. (Table XIV *b*).

The Kalianpur soil gave results to some extent similar to those of the Cawnpore soil, in that with the thirty milligrams dose of nitrogen, no nitrification took place in twenty-nine weeks when this was added as cyanamide, but though nitrification of cake and sulphate of ammonia took place, it was slower than in the Cawnpore soil. and not more than 50 per cent. of the added nitrogen was recovered as nitrate. (Table XV *a*). With a 5 mgms. dose of nitrogen as cyanamide, nitrification took place: but in the period of twenty-five weeks less than 40 per cent. of the added nitrogen was recovered as nitrate before the twenty-first week, and the proportion was 68 per cent. only in the twenty-fifth week.

The results given by the Karimganj soil were a striking contrast to those given by all the other soils tested.

In the first experiment with this soil, using the 30 mgms. dose, less nitrate was recovered in the thirty-two week period of the experiment when ammonium sulphate was added, than from the soil alone and nitrification of cake was so small as to be negligible. On the other hand, when cyanamide was added, nitrification started between the sixth and eleventh week, by the end of which time 32 per cent. of the added nitrogen was recovered as nitrate ; the maximum recovery, 67 per cent. was found after the twenty-fourth week. (Table XVI *a*). This result was so unexpected that the experiment was repeated (Table XVI *c*) and again no nitrification of sulphate of ammonia was observed in seventeen weeks. The cake had begun to nitrify, but the cyanamide had begun to nitrify between the eighth and thirteenth weeks, though not so rapidly as in the first experiment.

With the 5 mgms. dose of nitrogen as cyanamide, nitrification was never very vigorous and only 24 per cent. was recovered as nitrate, after seventeen to nineteen weeks' incubation (Table XVI *b* & *c*).

To see whether the presence of calcium cyanamide in a soil in which that substance nitrified slowly or not at all, checked the nitrification of other sources of nitrogen, two lots of Pusa soil were set up, to one of which was added cake to supply 30 mgms. of nitrogen per 100 gms. soil and to the other, cake to add 15 mgms. nitrogen per 100 gms. soil and calcium cyanamide to add a further 15 mgms. of nitrogen per 100 gms. soil. The Pusa soil taken was from a piece of land that had not been cultivated for some years, and in which the nitrifying bacteria were not very active.

The results are given in Table XVII below.

TABLE XVII.

Nitrification in Pusa soil.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.									
		Nitrogen recovered after week.									
		1	2	3	7	11	15	20	24	28	32
Soil + Cake	NO_3	0·9	10·8	13·2	13·2	18·0	21·6	19·2	19·2	..	..
	NO_2	0·22	0·02	0·01	trace	trace	trace	trace	trace	..	
	NH_3	8·8	5·6	3·6	4·8	4·4	5·2	4·0	4·8	..	..
Soil + equal parts cake and Cyanamide	NO_3	0·5	traces	traces	traces	2·7	7·8	7·2	9·6	13·2	12·0
	NO_2	0·04	0·04	0·03	0·09	0·06	trace	*nil*	*nil*	*nil*	*nil*
	NH_3	6·4	12·4	13·2	12·8	12·4	11·2	9·2	8·4	5·2	4·0

The presence of the cyanamide had therefore prevented the nitrification of the cake for the first eleven weeks ; and in three weeks the cake alone supplied as much nitrate as the mixture did in twenty-eight weeks. The highest nitrate figure for cake alone was 21.6 mgms. in the fifteenth week, and that for the mixture only 13.2 mgms. after twenty-eight weeks.

A further series of experiments was therefore started, using a different batch of Pusa soil, to see if the nitrification of sulphate of ammonia was hindered in the same way as that of cake. Five lots of soil were used. The treatments were as follows :—

I. Soil + Ammonium sulphate to add 30 mgms. nitrogen per 100 gms. soil.

II. Soil + Ammonium sulphate to add 15 mgms. nitrogen per 100 gms. soil, allowed to nitrify for one week, then cyanamide added to supply a further 15 mgms. nitrogen per 100 gms. soil.

III. Soil + Ammonium sulphate + Cyanamide, each to add 15 mgms. nitrogen per 100 gms. soil.

IV. Soil + Cyanamide to add 15 mgms. nitrogen per 100 gms. soil, then after one week, sulphate of ammonia added to supply a further 15 mgms. nitrogen per 100 gms. soil.

V. Soil + Cyanamide to add 30 mgms. nitrogen per 100 gms. soil.

Nitrate, nitrite and ammonia was estimated at the end of 1, 2, 4, 6 and 8 weeks in each of the five lots of soil, and the results are shown in Table XVIII below.

TABLE XVIII.

Treatment.	Nitrogen as	Mgms. nitrogen per 100 gms. soil after week.				
		1	2	4	6	8
I	NO_3	4·5	12·0	27·0	33·0	30·0
	NO_2	5·8	traces	traces	traces	traces
	NH_3	18·0	5·4	4·8	6·0	3·6
II	NO_3	4·5	4·5	4·5	5·3	3·8
	NO_2	7·8	6·6	5·3	3·7	traces
	NH_3	12·0	16·8	18·0	18·6	19·2
III	NO_3	1·2	2·3	2·3	3·0	3·0
	NO_2	1·0	0·1	0·03	0·2	traces
	NH_3	20·4	21·0	21·6	24·0	16·8
IV	NO_3	1·2	3·0	3·0	3·0	3·0
	NO_2	*nil*	1·3	*nil*	*nil*	*nil*
	NH_3	10·2	21·0	22·8	22·2	18·6
V	NO_3	1·2	1·8	3·0	3·0	3·0
	NO_2	*nil*	*nil*	*nil*	*nil*	*nil*
	NH_3	8·4	12·0	13·0	15·0	13·8

The adverse effect of the cyanamide on the nitrification of sulphate of ammonia is clearly indicated.

From II, it is seen that the nitrification which started is stopped by the addition of the cyanamide, and III & IV show that in the soil with addition of cyanamide at the same time as, or a week before, the addition of the sulphate of ammonia, nitrification is almost negligible.

The persistence of the nitrite nitrogen in II is to be noticed.

From Table V (*a*) it is seen that when 5 mgm. cyanamide nitrogen was added to Pusa soil, no nitrification took place in the first ten weeks. A further experiment was therefore started with two lots of Pusa soil. To e ch of them four mgms.

nitrogen per 100 gms. soil was added as ammonium sulphate, and allowed to nitrify for two weeks. At the end of this time, nitrogen as cyanamide was added to one lot of soil at the rate of 5 mgms. per 100 gms. soil and at 30 mgms. to the other, and estimations of nitrate, nitrite and ammonia done before the addition of the cyanamide and afterwards at the end of the first, second, fourth and sixth weeks. The results are given below.

TABLE XIX.

—	Nitrogen as	Mgms. nitrogen per 100 gms. soil.				
		Before addition of cyanamide	After addition of cyanamide—week.			
			1	2	4	6
Soil + 5 mgms. dose Nitrogen as cyanamide.	NO_3	4·5	5·3	6·8	7·5	9·0
	NO_2	*nil*	*nil*	*nil*	*nil*	*nil*
	NH_3	3·6	4·8	3·6	2·4	2·4
Soil + 30 mgms. dose Nitrogen as cyanamide.	NO_3	4·5	3·8	3·8	4·5	6·0
	NO_2	*nil*	*nil*	*nil*	*nil*	*nil*
	NH_3	2·7	15·6	13·2	12·6	10·8

From these results it appears that nitrification proceeded unchecked when the 5 mgms. dose was added, but was checked by the 30 mgms. dose for from four to six weeks.

Experiments in this laboratory have shown that when cake or sulphate of ammonia are added to Pusa soil so as to add 90 mgms. of nitrogen per 100 gms. soil, no accumulation of nitrate takes place, and ammonia produced by the nitrification of cake or added as sulphate of ammonia, gradually disappears. Soil from the borders of manure pits could however nitrify these quantities of ammonium sulphate or cake, and soil in which nitrification of 30 mgms. nitrogen per 100 gms. soil had proceeded for six weeks, and had then been washed free from nitrate, was able to nitrify up to 120 mgm. of added nitrogen per 100 gms. soil.

The nitrification of cyanamide in soil from the edge of a manure pit, was next investigated to see if in this soil cyanamide would nitrify readily or not.

Three lots of soil were taken, and cyanamide added in quantities to supply 5, 15 and 30 mgms. nitrogen per 100 gms. soil respectively.

The results are given in Table XX below.

TABLE XX

Nitrification of cyanamide in soil from edge of manure pit.

Amount of nitrogen as cyanamide added per 100 gms. soil	Nitrogen as	Mgms. nitrogen per 100 gms. soil found after week.				
		1	2	4	6	8
5 mgms	NO_3	2·4	1·8	4·5	5·4	7·5
	NO_2	0·1	1·0	1·2	traces	traces
	NH_3	10·9	10·9	8·4	3·0	2·1
15 mgms.	NO_3	2·4	3·0	7·2	10·5	11·2
	NO_2	0·1	0·2	traces	traces	traces
	NH_3	13·3	15·9	8·4	7·8	5·4
30 mgms.	NO_3	2·4	2·4	3·8	3·8	3·8
	NO_2	0·1	0·1	traces	traces	traces
	NH_3	18·5	14·3	14·3	8·4	10·2

Thus with the 5 mgms. and 15 mgms. dose nitrification had made fair progress by the fourth week, and continued steadily for the remaining four weeks of the experiment. The 30 mgms. dose again checked nitrification.

A further attempt was then made to try and nitrify cyanamide when this was added to supply nitrogen at the rate of 30 mgms. per 100 gms. soil.

Manure pit soil was allowed to nitrify ammonium sulphate, the nitrate washed out, and cyanamide added to supply 30 mgms. nitrogen per 100 gms. soil. As a check, and to make sure that vigorous nitrification could take place in the soil, to a second portion of washed soil, sulphate of ammonia was added to supply an equal quantity of nitrogen. The results of this experiment are given in Table XXI.

Table XXI.

Nitrification in soil from edge of manure pit, washed to remove excess of nitrate after nitrification of ammonium sulphate.

—	Nitrogen as	Initial.	30 Mgms. nitrogen added per 100 gms. soil. Mgms. nitrogen per 100 gms. soil found after week. 1	2	4	6	8
Soil + Cyanamide . .	NO_3	4·2	6.0	6·8	9·0	12·0	13·5
	NO_2		0·1	0·3	traces	traces	traces
	NH_3		16·8	20·2	12·0	11·4	10·2
Soil + Ammonium Sulphate	NO_3	4·2	34·5	30·0	34·8	..	..
	NO_2		*nil*	*nil*	*nil*	..	..
	NH_3		6·7	11·8	9·6	..	..

At the end of the fourth week, the soil to which the sulphate of ammonia had been added was washed free from nitrate, cyanamide added to supply 5 mgms. nitrogen per 100 gms. of soil, and again incubated. The nitrogen recovered after 1, 2, and 4 weeks' incubation is shown in Table XXII,

Table XXII.

Nitrification of cyanamide in manure pit soil from the previous experiment. Soil washed free from nitrate, and cyanamide added to supply 5 mgms. nitrogen per 100 gms. soil.

Nitrogen as	Initial	Mgms. nitrogen found after week. 1	2	4
NO_3	*nil*	1·2	4·5	5·4
NO_2	..	traces	traces	traces
NH_3	..	4·2	1·2	1·2

Here for the first time in a Pusa soil we find an appreciable quantity of nitrogen supplied as cyanamide at the rate of 30 mgms. nitrogen per 100 gms. soil being nitrified in an incubation period of four to eight weeks. Nitrification of a 5 mgm. dose proceeded more rapidly in this washed soil than it did in ordinary Pusa soil in which a 4 mgm. dose of nitrogen as sulphate of ammonia had been allowed to nitrify for two weeks before the addition of the cyanamide (Table XIX).

As nitrification of cyanamide was found to take place in Pusa soil which possessed an exceptionally high nitrifying power, the addition of a culture of nitrifying organisms to ordinary Pusa soil was tried to see if by this means nitrification of cyanamide could be stimulated.

To each of three lots of Pusa soil, cyanamide was added to supply nitrogen at the rate of five, fifteen and thirty mgm. per 100 gms. soil. A culture of nitrifying bacteria was added, the soils incubated, and the usual estimations done at intervals through eight weeks. The results are given in Table XXIII. The amount of nitrate added with the nitrifying culture has been subtracted from the figures for nitrate.

Table XXIII.

Nitrification of cyanamide in Pusa soil to which a culture of nitrifying bacteria has been added.

Nitrogen added as cyanamide per 100 gms soil.	Nitrogen as	Mgm. nitrogen per 100 gms. soil found after week.				
		1	2	4	6	8
5 mgms.	NO_3	1·8	3·0	6·0	6·0	7·5
	NO_2	traces	traces	traces	traces	traces
	NH_3	4·8	4·8	2·7	2·1	1·8
15 mgms.	NO_3	2·4	3·0	6·0	6·0	7·5
	NO_2	traces	traces	traces	traces	traces
	NH_3	12·6	13·8	13·2	10·2	8·4
30 mgms.	NO_3	2·4	3·8	4·5	4·5	6·0
	NO_2	traces	traces	traces	traces	traces
	NH_3	13·2	13·2	15·0	13·2	10·8

Nitrification has proceeded well with the 5 mgms. dose and with the 15 mgms. dose the same quantity of nitrate was recovered as with the 5 mgms. dose.

The 30 mgms. dose again retarded nitrification but not to such an extent as it did in ordinary manure pit soil or Pusa soil with no addition of nitrifying culture.

Owing to the acid nature of the Karimganj soil, an additional series of experiments was carried out, in which one per cent. by weight of calcium carbonate was added to the soil, and the nitrification of cake, ammonium sulphate and cyanamide again tested. The addition of the calcium carbonate changed the pH of the soil from 4·9, the original value, to 7·6.

From the results of this series given in Tables XXIV (a) and (b) it is seen that nitrification of both cake and ammonium sulphate had started by the end of the fourth week and was going on actively till the end of the experiment, in the eighth week. When a 30 mgms. dose of nitrogen was added as cyanamide, there was no nitrification in eight weeks, and far less nitrate was found than was recovered from soil with the addition of calcium carbonate only. In the latter case the very large quantity of 12 mgms. of nitrate was recovered from the original organic nitrogen of 100 gms. soil. When only five mgms. of nitrogen were added as cyanamide, nitrification was rather less than in the control for the first six weeks of the experiment, but by the eighth week a quantity of nitrate greater than that from the control was recovered.

TABLE XXIV (*a*).

Nitrification in Karimganj soil to which 1 per cent. calcium carbonate was added.

—	Nitrogen as	30 Mgms. nitrogen added per 100 gms. soil.				
		Mgms. nitrogen found after week.				
		1	2	4	6	8
Soil + Cyanamide	NO_3	2·1	1·8	1·5	2·4	3·0
	NO_2	0·1	trace	trace	trace	0·1
	NH_3	21·6	21·6	22·8	21·6	26·0
Soil + Ammonium sulphate	NO_3	2·1	2·1	6·6	28·8	33·6
	NO_2	0·1	trace	1·7	0·1	0·1
	NH_3	24·4	24·0	14·8	1·2	0·8
Soil + Cake	NO_3	3·0	3·0	7·2	24·0	28·8
	NO_2	0·1	trace	1·6	0·1	0·1
	NH_3	16·0	16·8	10·8	1·2	0·8
Soil — No added nitrogen	NO_3	3·6	4·2	4·8	9·6	12·0
	NO_2	0·2	0·1	trace	trace	trace
	NH_3	3·6	4·8	5·0	1·2	1·2

TABLE XXIV (*b*).

Nitrification in Karimganj soil with 1 per cent. calcium carbonate added, and 5 mgms nitrogen per 100 gms. soil.

—	Nitrogen as	Mgms. nitrogen found after week.				
		1	2	4	6	8
Soil + Cyanamide 5 mgms. N.	NO_3	3·3	3·3	4·2	7·2	15·6
	NO_2	0·4	0·1	trace	0·1	trace
	NH_3	6·8	8·0	8·0	5·6	0·8

Summary.

In all but one of the soils examined, nitrification of sulphate of ammonia and of cake began before that of cyanamide.

When cyanamide was added in quantities to supply 30 mgms. nitrogen per 100 gms. soil, some weeks always passed before nitrification began, and in Pusa soil even after twenty six. in Cawnpore and Kalianpur soils, after twenty-nine weeks, nitrification had not begun.

In the Ranchi soils, the better the soil, the quicker nitrification was in starting. In the Upland soil, it began after twenty eight weeks, in the Intermediate soil after twenty weeks, and in the Valley soil it was just beginning after sixteen weeks, and was rapid in the next five weeks.

In Chinsurah soil, vigorous nitrification did not begin till after the twenty-fourth week, but even after forty weeks less than half the added nitrogen was recovered as nitrate.

In Kalol soil, nitrification started after the fifteenth week.

In Sihar soil, nitrification of cyanamide was most rapid. It started vigorously between the eighth and tenth weeks, and by the end of the fourteenth week, equalled that of sulphate of ammonia.

The Karimganj soil is abnormal. Nitrification of the cyanamide started after the sixth week, 9·6 mgms. nitrate nitrogen were recovered by the 11th week, and 20·1 mgms. by the twenty-fourth. When sulphate of ammonia or cake was added, there was practically no nitrification of either of them, owing to the acid nature of the soil. Correction of the acidity by liming enabled nitrification to take place readily with sulphate of ammonia and cake, but that of cyanamide had not started in eight weeks.

When cyanamide was added in doses to supply 5 mgms. nitrogen per 100 gms. soil, nitrification began earlier than with 30 mgms. dose. In Pusa soil it was slow, but in four months sixty per cent. of the added nitrogen was recovered as nitrate,

in the Cawnpore and Kalianpur soils in which, with Pusa soil, there had been no nitrification of the 30 mgms. dose, sixty and forty-eight per cent. respectively of the added nitrogen was recovered as nitrate at the end of ten weeks.

When 30 mgms. nitrogen per 100 gms. soil, are added to Pusa soil, half as cake or as ammonium sulphate and half as cyanamide, the cyanamide prevents nitrification for several weeks.

In Pusa soil of exceptionally high nitrifying power, in which 30 mgms. ammonium sulphate nitrified in a week, nitrification with the 30 mgms. dose of cyanamide began by the first week, and went on slowly till nitrate equivalent to thirty per cent. of the added nitrogen was recovered after eight weeks.

Cowie* found no evidence of nitrification of dicyanodiamide after several months, in some English soil, and that dicyanodiamide is toxic to the nitrifying organisms and stops the normal oxidation of ammonia in soils containing ammonium sulphate, as well as that of the ammonia produced from cyanamide in soils. He found that the cyanamide readily broke down in the soil, yielding ammonia, which then nitrified in the usual way.

The cyanamide used in our experiment with the Indian soils was free from dicyanodiamide, but nitrification with the large dose, 30 mgms. per 100 gms. soil was always retarded for some weeks, even in soils which nitrified cake or ammonium sulphate vigorously, and in which a large part of the cyanamide was recovered as ammonia after an incubation period of one week. The addition of cyanamide seems to give rise to some factor inhibiting the action of the nitrifying organisms in the soil, and until this disappears the normal nitrification processes do not begin.

I have to thank my assistants, Messrs. Har Dayal Singh, B.Sc., and B. K. Das Gupta, B.A., for the help they gave with the analytical work.

Cowie * Decomposition of Cyanamide and Dicyanodiamide in the soil. *Jour. Agric. Science*, Vol. IX, p. 113 (1919).

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